

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

## Messinian to Zanclean vegetation and climate of Northern and Central Italy

### This is the author's manuscript

*Original Citation:*

*Availability:*

This version is available <http://hdl.handle.net/2318/57252> since

*Terms of use:*

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

# Messinian to Zanclean vegetation and climate of Northern and Central Italy

Adele BERTINI & Edoardo MARTINETTO

A. Bertini, Dipartimento di Scienze della Terra, Via G. la Pira 4, I-50121 Firenze, Italy; adele.bertini@unifi.it

E. Martinetto, Dipartimento di Scienze della Terra, Via Valperga Caluso 35, I-10125 Torino, Italy; edoardo.martinetto@unito.it

**KEY WORDS** - Flora, Vegetation, Pollen, Macroremains, Messinian, Zanclean, Italy.

**ABSTRACT** - A comparative analysis of micro (pollen)- and macropalaeobotanical (leaves, fruits and seeds) data from selected Northern and Central Italy sites has been carried out in order to obtain an accurate interpretation of the palaeofloristic, vegetational and climatic setting for the Messinian and the Zanclean. Ancient plant communities, as reconstructed by means of this integrated approach, show the dominance of warm temperate forest taxa, with the highest floristic affinity to the forests of Central China. "Cool temperate" taxa are scarcely represented in pollen records, with the exception of some intervals characterized by the increase in *Picea* and *Cedrus*. The overall scantiness of herbs indicates the absence of dry conditions and no open vegetation expansion. All the analytic methods applied to such palaeofloral records indicate that precipitation was sufficiently high for the persistence of a "broad-leaved evergreen/warm temperate mixed forest" from 6.0 to 3.5 Ma. For the evaporitic Messinian (ca. 5.9 to 5.6 Ma), climatic reconstructions obtained by physiognomic analysis of leaf assemblages are in agreement with those based on pollen data according to the "Climatic Amplitude Method", and indicate moist warm-temperate conditions. Accordingly, we suggest that the Adriatic-Padane basin would have been under dominant moist conditions, even during the deposition of evaporites. Slightly drier phases in post-evaporitic Messinian are suggested by the ecological preferences of some peculiar macrofossil taxa, which are, however, still associated to several arboreal plants, definitely indicating that forested environments persisted. Fluctuations in humidity are also attested by contemporary pollen records.

**RIASSUNTO** - [Vegetazione e clima in Italia centro-settentrionale durante il Messiniano e lo Zancleano] - Le analisi sui resti micro- e macroscopici di piante terrestri delle successioni messiniane e zancleane dell'Italia centro-settentrionale, effettuate nel corso dell'ultimo ventennio, hanno restituito un record paleofloristico ricco e diversificato. I resti fossili di foglie, frutti e semi rappresentano, storicamente, la prima fonte d'informazione paleobotanica, accresciuta in questi ultimi anni dall'utilizzo di nuovi metodi di preparazione (paleocarpologia) e analisi (fisionomia delle foglie). La documentazione macrofloristica, nonostante sia spesso puntiforme e limitata alla ricostruzione dell'ambiente locale, offre il vantaggio di una più precisa determinazione a livello specifico rispetto a quanto non consenta la palinologia. Quest'ultima rimane tuttavia il metodo più efficace per la ricostruzione della flora, della vegetazione e degli ambienti continentali del Messiniano e dello Zancleano grazie ad altre utili peculiarità dei granuli pollinici, per esempio la loro larga diffusione spaziale e temporale nonché notevole preservazione in depositi non solo continentali ma anche marini. Prerogative del record palinologico rispetto a quello macrofloristico sono di documentare piani vegetazionali diversi (ad esempio una più ampia documentazione della biodiversità) e non esclusivamente ambienti locali e di estendere, talvolta in modo notevole, la puntiforme documentazione temporale dei macroresti. Le diverse caratteristiche delle due metodologie non sono state comunque messe in contrapposizione, ma anzi al fine di giungere ad una quanto più accurata e aggiornata interpretazione della paleoflora e della vegetazione abbiamo deciso di integrare, confrontandoli, i dati pollinici e macropaleobotanici provenienti dai numerosi siti neogenici del bacino del Po e dell'Appennino settentrionale. Il considerevole aumento della documentazione negli ultimi due decenni ci ha consentito di rendere più significativi i risultati dell'analisi comparata. L'analisi paleoclimatica di tutti i dati paleofloristici disponibili nell'intervallo tra 6.0 e 3.5 Ma indica condizioni temperato-calde e precipitazioni elevate, tanto da consentire la persistenza in Italia centro-settentrionale di una "foresta mista di latifoglie sempreverdi/temperato-calda". I taxa "fresco-temperati" sono generalmente poco rappresentati, con episodico aumento percentuale del polline di *Picea* e *Cedrus*, probabile indicazione di leggero raffrescamento. La scarsa abbondanza del polline di piante erbacee suggerisce l'assenza di vegetazione aperta e quindi di dominanti condizioni aride, come confermato anche dai seppure più scarsi dati macrofloristici. Durante la fase evaporitica, tra 5.9 e 5.6 Ma, le ricostruzioni climatiche ottenute analizzando i dati pollinici con il "Climatic Amplitude Method" sono in accordo con quelle basate sull'analisi fisionomica delle associazioni fogliari nell'indicare una piovosità elevata. La deposizione delle evaporiti nel Bacino Adriatico-Padano sarebbe quindi avvenuta sotto condizioni climatiche prevalentemente umide. Nel corso del tardo Messiniano, la registrazione macropaleobotanica testimonia la presenza di alcuni taxa peculiari (*Medicago*, *Vitex*), possibili indicatori di condizioni stagionalmente più aride. La presenza di fluttuazioni nei valori dell'umidità è testimoniata anche dalla registrazione pollinica, che mostra fasi di incremento ora delle conifere meso-microterme (*Tsuga* e *Cedrus*) ora dei taxa erbacei tipici di ambienti aperti. Le comunità di piante terrestri del Messiniano e dello Zancleano, come ricostruite attraverso questo approccio integrato, mostrano la più alta affinità floristica con le attuali foreste diffuse sui rilievi della Cina centrale in condizioni climatiche temperato-calde (temperatura media annua tra 17-14°C) e umide (precipitazioni medie annue superiori a 1000 mm).

## INTRODUCTION

The Messinian Salinity Crisis remains one of the most studied, although not necessarily well understood, events of the Neogene, as testified by the different scenarios and chronostratigraphic frameworks proposed to explain its development (e.g. Butler et al., 1995; Clauzon et al., 1996; Krijgsman et al., 1999a, b; Rouchy & Caruso, 2006; Roveri & Manzi, 2006; Roveri et al., 2008 and references

therein). There is a general agreement on the onset of the evaporitic deposition, since cyclostratigraphic studies suggest this was a synchronous event, occurring at  $5.96 \pm 0.02$  Ma in the Central to Western Mediterranean (Krijgsman et al., 1999a, b). On the contrary, the chronology of the post-evaporitic Messinian, including the *Lago-Mare* event marked by the occurrence of plant and invertebrate taxa with Paratethyan affinities (e.g. Hsu et al., 1978; Corselli & Grecchi, 1984), is more

controversial (e.g. Clauzon et al., 2005; Bertini, 2006; Popescu et al., 2007; Roveri et al., 2008). In the Northern Apennines post-evaporitic sedimentation starts close to 5.6 Ma and it is expressed by two main depositional sequences (p-ev<sub>1</sub> and p-ev<sub>2</sub>) separated by an unconformity (Roveri et al., 2001, 2008). Different stratigraphical frames have been postulated for other post-evaporitic deposits, notably the Sicilian ones (e.g. Clauzon et al., 1996; Krijgsman et al., 1999a, b; Roveri et al., 2008). At 5.33 Ma the flooding of the Mediterranean basin by Atlantic waters produces a new scenario for both the aquatic and terrestrial realms. Accordingly during the Messinian and the Zanclean, Mediterranean aquatic environments experienced dramatic changes in water basin level, drainage system, salinity as well as faunal and floral assemblages, as documented by numerous studies (e.g. Rouchy et al., 2006 and references therein). Yet, few papers analysed the contemporaneous status of Peri-Mediterranean terrestrial vegetation and biomes.

We intend to carry out such an analysis in Northern and Central Italy, where thick and well-exposed Messinian and Zanclean successions (Fig. 1) provided rich palaeofloral records, thanks to the abundance of both

micro- and macroscopic remains of terrestrial plants. Fossil leaves, fruits and seeds have been the earliest historical source of information on the Messinian to Zanclean palaeoflora and vegetation (Viviani, 1833; Massalongo, 1854; Massalongo & Scarabelli, 1859) and fresh information has been recently provided (Kovar-Eder et al., 2006) by peculiar methods of preparation (palaeocarpology) and analysis (leaf physiognomy: Martinetto et al., 2007a). Nowadays, however, palynology represents one of the most significant tools for the reconstruction of flora, vegetation and environment due to the well-known methodological advantages and because pollen grains can be retrieved in large quantity throughout thick successions of both continental and marine deposits (e.g. Suc et al., 1995a, b; Bertini, 2002, 2006).

Consequently, micro- and macrofloral evidence can contribute significantly to the reconstruction of the spatial and temporal modifications that affected Mediterranean terrestrial ecosystems during the Messinian and the Zanclean, including the evaporitic phase, the *Lago-Mare* event and the following marine transgression (see references in Suc & Bessais, 1990;

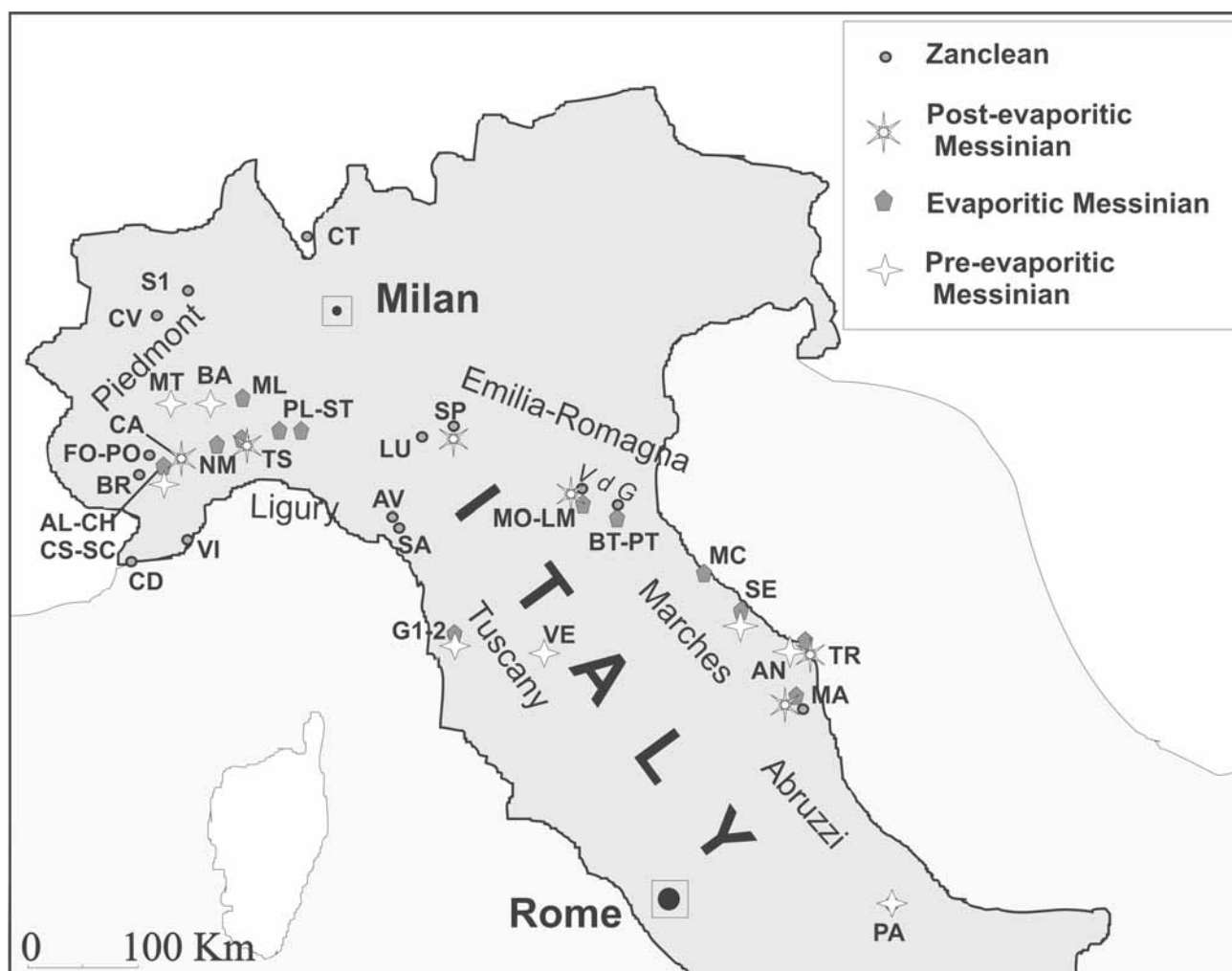


Fig. 1 - Map of Northern and Central Italy showing the location of the fossil sites cited in the text. VdG = Vena del Gesso Basin. For locality labels see explanation in Tab. 1.

Bertini, 1992; Suc et al., 1995a, b; Bertini et al., 1998; Bertini, 2006; Kovar-Eder et al., 2006). In Italy abundant pollen data, recently summarized by Bertini (2002, 2006), are available for several sites, which have a widespread geographic distribution and a detailed stratigraphic framework (Fig. 1). Such data were also successfully used for climate quantification (Fauquette & Bertini, 2003; Fauquette et al., 2006). The pollen-bearing sites, however, rarely yield plant macrofossils, which have been mostly studied in different localities, as reported by Kovar-Eder et al. (2006) and Martinetto et al. (2007a).

This paper aims at summarizing the information provided by palaeobotanical records (micro- and macroflora), which are deemed useful for a revised and standardized reconstruction of vegetation and climate from Messinian to late Zanclean. In particular, we point to enhance the reconstructions' accuracy by integrating multiple records (pollen, fruits, leaves) of terrestrial plant communities collected from short portions of key successions. The analysis and discussion are based on data collected during the authors' research, integrated with information provided by other palaeobotanical studies (Tab. 1).

Label	Sites	Italian region	Stratigraphy	Palaeobotanical references	Palaeobotanical data sets
AL	Monticello d'Alba	Piedmont	evaporitic Messinian (Vena del Gesso Fm)	Kovar-Eder et al. 2006	leaves
AN	Ancona	Marches	evaporitic Messinian	Paolucci 1896	leaves
AV	Aulla- Vallescura	Tuscany	Zanclean or Piacenzian (continental deposits)	Bertoldi 1988; Bertoldi et al. 1994	pollen
BA	Banengo	Piedmont	pre-evaporitic Messinian (marine deposits)	Kovar-Eder et al. 2006	leaves
BR	Breolungi	Piedmont	Zanclean (marine deposit, (Argille Azzurre)	Cavallo & Martinetto 1996	carpoids
BT	Borgo Tossignano (Vena del Gesso basin)	Emilia-Romagna	evaporitic Messinian (Vena del Gesso Fm)	Bertini 1992; Bertini 1994b; Bertini 2006	pollen, leaves
CA	Corneliano d'Alba (composite section Sioneri-Ciabot Cagna)	Piedmont	evaporitic Messinian (Vena del Gesso Fm) & post-evaporitic Messinian (Cassano-Spinola Conglomerates)	Lanini 2001; Bertini 2006	pollen, carpoids, leaves
CD	Castello d'Appio	Liguria	Zanclean (marine deposits)	Zheng 1990	pollen
CH	Cherasco	Piedmont	Messinian (Vena del Gesso Fm)	Lanini 2001, Bertini 2006	pollen
CS	Castagnito	Piedmont	Messinian (Vena del Gesso Fm)	Martinetto et al. 2000; Kovar-Eder et al. 2006	leaves
CT	Castel di Sotto	close to Lombardy	Pliocene, most probably late Zanclean (marine deposits)	Brambilla 1992b	leaves
CV	Ca' Viettone	Piedmont	Pliocene, most probably late Zanclean (continental deposits)	Allason et al. 1981; Bertoldi & Martinetto 1996	pollen, carpoids, leaves
FO	Fossano	Piedmont	Pliocene, most probably late Zanclean (continental deposits)	Martinetto et al. 2007b	pollen, carpoids, leaves
G1	Gabbro I	Tuscany	pre-evaporitic Messinian (marine deposits)	Trevisan 1967	pollen, leaves
G2	Gabbro II	Tuscany	Messinian (post-evaporitic continental deposits )	Trevisan 1967	pollen, leaves
LM	Cava Li Monti (Vena del Gesso Basin)	Emilia-Romagna	Messinian ( Euxinic shales & Vena del Gesso Fm)	Bertini 1992; 1994a, b; 2006	pollen
LU	Lugagnano	Emilia-Romagna	Zanclean (marine deposit)	Gregor 1990	carpoids
MA	Maccarone	Marches	Zanclean (Argille Azzurre) & Late Messinian (p-ev1 and p-ev2)	Bertini 1992; Bertini 1994a, b; Bertini 2006	pollen
MO	Monticino '87 (Vena del Gesso basin)	Emilia-Romagna	Zanclean (Argille Azzurre) & Late Messinian (p-ev2)	Bertini 1992; Bertini 1994a, b	pollen
MC	Monte Castellaro	Marches	evaporitic Messinian	Gentilini 1989	leaves
ML	Monte Castello	Piedmont	Messinian (?Vena del Gesso Fm)	Peola 1899b	leaves
MT	Moncuoco Torinese	Piedmont	pre-evaporitic Messinian (marine deposits)	Violanti et al. 2003	leaves
NM	Nizza Monferrato	Piedmont	evaporitic Messinian (?Vena del Gesso Fm)	Brambilla & Gallo 2002	leaves
PA	Palena	Abruzzi	pre-evaporitic Messinian (marine deposits)	Kovar-Eder et al. 2006	leaves
PL	Portaibera	Lombardy	evaporitic Messinian	Brambilla 1992a	leaves
PO	Pocapaglia	Piedmont	Zanclean (marine deposit)	Cavallo & Martinetto 1996	carpoids
PT	Polenta	Emilia-Romagna	Messinian (?Vena del Gesso Fm)	Principi 1926	leaves
RO	Roddi	Piedmont	pre-evaporitic Messinian (marine deposits)	Kovar-Eder et al. 2006	leaves
S1	Sento I	Piedmont	Zanclean (marine deposit)	Basilici et al. 1997	carpoids
SA	Sarzana	Liguria	Zanclean or Piacenzian (continental deposits)	Bertoldi et al. 1994	pollen
SC	Scaparoni +Piobesi	Piedmont	evaporitic Messinian	Lanini 2001, Bertini 2006	pollen, leaves
SE	Senigallia	Marches	evaporitic Messinian	Massalongo & Scarabelli 1859	leaves
SP	Scipione Ponte-Stirone	Emilia-Romagna	Late Messinian (post-evaporitic deposits) - Zanclean - Gelasian (Argille Azzurre)	Bertini 1992; 1994a, b; 2001; Lanini 2001; Fauquette & Bertini 2003	Messinian: pollen, carpoids; Zanclean: pollen
ST	Stradella (Montescano flora)	Lombardy	evaporitic Messinian (?Vena del Gesso Fm)	Viviani 1833; Sordelli 1896	leaves
TR	Trave	Marches	LateTortonian/Messinian (pre-evaporitic, p-ev1, p-ev2)	Iaccarino et al. submitted	pollen
TS	Torre Sterpi+Carbonara Scrivia	Piedmont	evaporitic (C. S.) and post-evaporitic (T. S.) Messinian deposits	Sachse 2001; Brambilla et al. 1982	pollen, leaves, few carpoids
VE	Velona	Tuscany	pre-evaporitic Messinian (continental deposits)	Ghetti et al. 2002	pollen
VI	Cava di Villanova	Liguria	Zanclean (marine deposits)	Zheng 1990	pollen

Tab. 1 - List of the Messinian-Zanclean sites with palaeofloral data discussed in this paper.



## MATERIALS AND METHODS

The micro- and macro-palaeobotanical records analysed in this paper were collected from different outcrops of the western and eastern sectors of the Northern Apennines and Piedmont (Fig. 1 and Tab. 1). Palaeobotanical data are chronologically framed and discussed on the basis of the stratigraphic and geological evidence from Irace et al. (2005) and Roveri et al. (2003, 2004, 2008).

Those sections in which rich palynofloras were associated to diversified macrofossil assemblages were analysed in greater detail (Tab. 1). However, their restricted chronologic and geographic distribution would not allow a thorough reconstruction of vegetation and climate for Northern-Central Italy without a reconsideration of several successions which yielded a single type of record, either pollen, leaves or carpological remains.

Pollen samples were generally submitted to standard chemical-physical procedures including treatments with HCl (10%), HF (48%), KOH (10%), ZnCl<sub>2</sub> separation (solution density ca. 2.0); more details on preparation techniques and identification of pollen taxa are described by Bertini (1992). Detailed results and synthetic palynological diagrams are described by Bertini (1992, 2002, 2006), Lanini (2001), Ghetti et al. (2002), Iaccarino et al. (in press). Carpological remains ("carpoids") were prepared by means of bulk sediment sieving according to the method described by Martinetto (1994) and Basilici et al. (1997). Methods for leaf analysis and extraction of palaeoclimatic signals are described by Kovar-Eder et al. (2006) and Martinetto et al. (2000, 2007a).

Methods applied to reconstruct vegetation are inspired to Van der Burgh (1983), Van der Burgh & Zetter (1998), Meller et al. (1999) and Grimmson et al. (2007), however we avoided to split so many vegetation units as recognised by Van der Burgh (1983).

A sketchy reconstruction of vegetation distribution was plotted on a transect running from undifferentiated relieves to coastal areas, without hazardous tentatives to further differentiate the palaeoenvironment (Fig. 2). The different dispersion spectra of plant macroremains and pollen (Ferguson, 1995), found in the same deposit, allowed us to infer the distance of the growth place of most plant taxa from the deposition site. In general, we considered as montane trees those woody plants which, in pre-Gelasian deposits (preceding the onset of glacial-interglacial cycles, with consequent drastic vegetation change), are documented only by pollen, and whose modern plant analogs typically grow on high to middle uplands (*Abies*, *Cedrus*, *Picea*). On the other hand, the frequent occurrence of macroremains has been considered an indication for plants that grew closer to lowland depositional basins (Spicer & Wolfe, 1987). A basin-scale extension of this analysis gave support to the hypotheses drawn from the study of individual fossil sites.

Synthetic palaeoclimatic data have been gathered by integrating the results of different methods employed to unlock the signals recorded by pollen diagrams, leaf assemblages and carpological floras. Pollen data have been recently analysed from twenty-one Messinian and

Zanclean successions in the peri-Mediterranean region according to the "Climatic Amplitude Method" (CAM; Fauquette et al., 1998a, 1999, 2006, 2007) and the Coexistence approach (CA; Bruch et al., 2002), which has also been applied to the Zanclean macroflora of Fossano (Martinetto et al., 2007b). Physiognomic analysis has been employed for the "Alba" leaf floras (Martinetto et al., 2007a). Finally, the so-called Nearest Living Relative (NLR) method (Collinson, 1986) was largely used for both carpological and pollen floras, because most taxa can be assigned to modern genera, thus permitting to exploit the climatic requirements of their recent relatives for palaeoclimate reconstruction. In this respect several taxa have been assigned to the megatherm, mesotherm and microtherm thermal zones after Schimper (1898) and Nix (1982). The term "subtropical" is here used *sensu* Hou (1983), and therefore includes the southern part of the warm-temperate zone (i.e. Central and Southern China) of the Köppen classification system.

## FLORA AND VEGETATION STRUCTURE

### *Flora - general features*

The Messinian - Zanclean flora of Italy can be mainly reconstructed on the basis of palynological remains, which are often associated in high-diversity assemblages: for example Messinian deposits of Piedmont and Emilia-Romagna provided up to 135 pollen taxa (e.g. Bertini, 1992, 2002, 2006; Lanini, 2001). Carpological remains allow to refine the identification of some botanical taxa or to detect additional floral elements which are not recorded in the palynoflora, yet only in the post-evaporitic Messinian and late Zanclean. In the evaporitic interval the carpological record is particularly scanty, and the overwhelming record of leaf remains, which are not always suitable for a sound botanical identification, just allows to point out the effects of some taphonomical biases affecting the pollen record, e.g. the lack of Lauraceae, which have pollen grains with a very thin and decay-prone exine.

The type of palaeoflora we could reconstruct on the basis of pollen, leaves or fruits was basically very similar in the whole Messinian to late Zanclean interval, even if peculiar features of a few time slices will be discussed below. Such palaeoflora is partly made up by genera still living in Europe, as well as genera presently absent in the native flora ("exotic": Reid, 1920) and restricted to East Asia and/or North America. An Asian-American disjunction is displayed by *Chamaecyparis*, *Thuja*, *Ampelopsis*, *Aralia*, *Cephalanthus*, *Liquidambar* (Pl. 2, fig. 10), *Liriodendron*, *Magnolia*, *Mahonia*, *Meliosma*, *Sassafras*, and *Symplocos*. Additionally, *Sequoia* is presently confined to North America. The exclusively East Asian component prevails: *Cephalotaxus*, *Cryptomeria*, *Ginkgo*, *Glyptostrobus*, *Actinidia*, *Cinnamomum*, *Craigia*, *Eurya* s.s., *Hartia*, *Mallotus*, *Microtropis*, *Paulownia*, *Phellodendron*, *Pterocarya*, *Rehderodendron*, *Reevesia*, *Rhoiptelea* (Pl. 2, fig. 4), *Sabia*, *Sciadopitys*, *Sinomenium*, and *Toddalia*.

Pollen grains of several taxa, which are found today in climatically contrasting regions, are often associated in individual samples. Some tropical taxa (e.g. *Agave*,

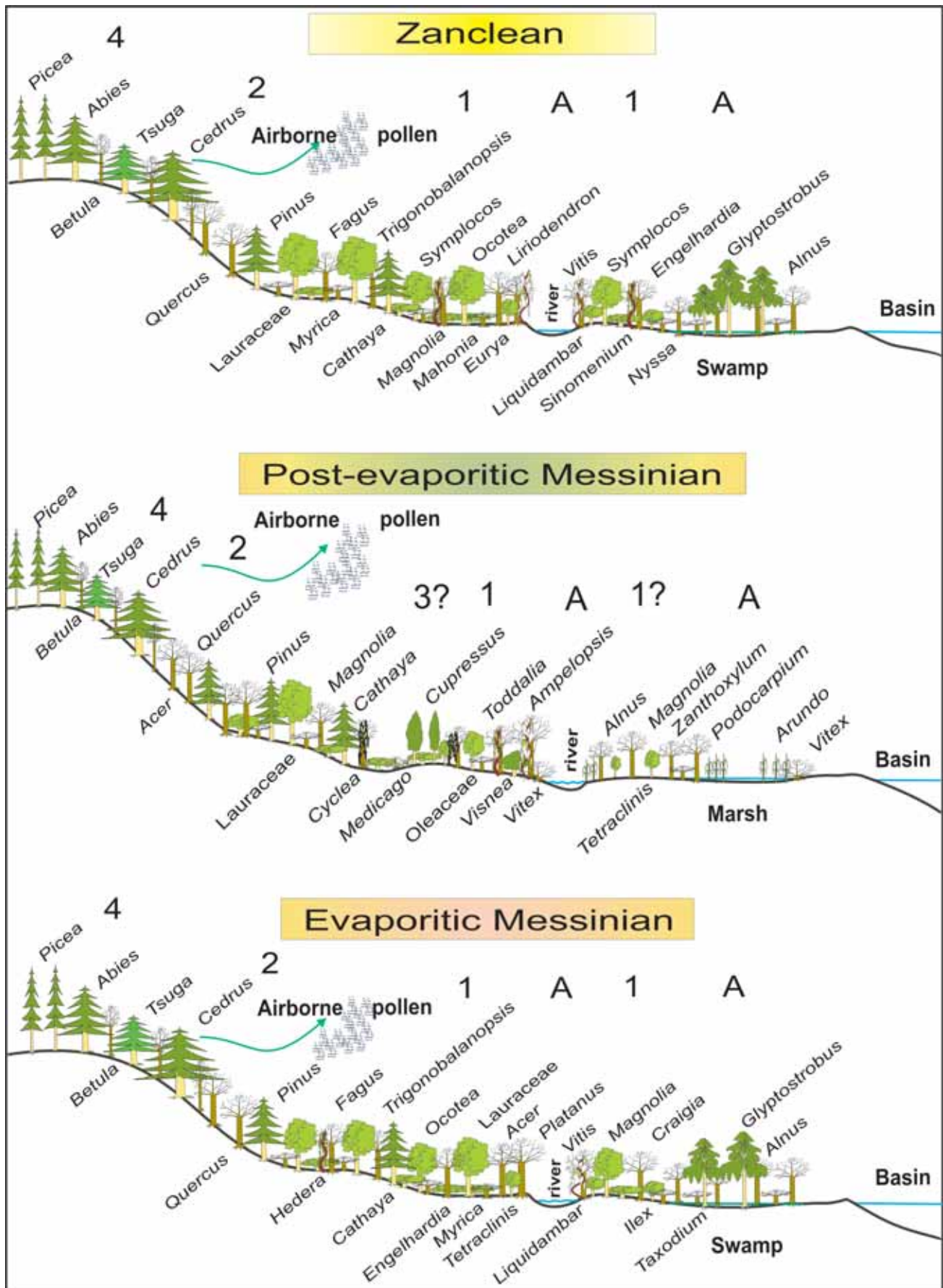


Fig. 2 - Sketchy reconstruction of Northern and Central Italian vegetation in the evaporitic Messinian, in the post-evaporitic Messinian (mainly based on the records from Scipione Ponte and Sioneri) and Zanclean. A: azonal vegetation types. 1, 2, 3, 4 refer to "formation classes" as numbered in Tab. 2.

*Cordyline*, *Nolina*, *Sindora*, *Alchornea*, *Canthium* type) were recorded, though sporadically and always with very low percentage, in the Messinian of some Central Italian sites (e.g. Maccarone, post-evaporitic Messinian: Bertini, 1992, 1994a, b). No macrofossil record is available for such plants, and probably long distance transport should be considered for their interpretation. Reworking from older sediments is unlikely because pollen grains of such taxa are always poorly concentrated in Cenozoic sediments, and a clear southward increase in their concentration was observed in Messinian sites (Suc & Bessais, 1990; Suc et al., 1995a, b; Bertini et al., 1998).

On the other hand, the local presence of Arecaceae, mainly tropical-subtropical, is demonstrated by the occurrence of leaves in the pre-evaporitic Messinian at Roddi (cf. *Sabal*) and Palena (cf. *Calamus*: Pl. 1, fig. 9). These leaves are similar to those of modern forms, which tolerate warm-temperate climate (*Sabal palmetto* Lodd. ex J. A. & J. H. Schult., *Calamus palustris* Griffith.). In the Vena del Gesso evaporitic sediments and in post-evaporitic and Pliocene deposits palm leaves have not been detected, yet pollen grains of Arecaceae were recovered in both Messinian and Zanclean deposits.

As for the Gymnosperms, the *Taxodium*/*Glyptostrobus* type (Pl. 2, fig. 15) is commonly represented in pollen records. Shoots of both *Glyptostrobus* and *Taxodium* are common in the evaporitic Messinian, thus proving that these plants grew in lowlands close to the depositional environments. They are interpreted as “subtropical” and warm temperate taxa. Furthermore, the ecological requirements of the modern representatives of these two genera (Farjon, 2005) would suggest that they grew in permanently waterlogged conditions (swamps), unlike *Sequoia* and *Cryptomeria* (whose shoots are equally common in the evaporitic Messinian), which would grow in better-drained areas.

*Sciadopitys* is often common in Messinian-Zanclean pollen records, but extremely scanty in the macrofossil record (a single needle-leaf in the evaporitic Messinian

of Alba: Guglielmetto & Iguera, 1994), which is consistent with an upland distribution.

The occurrence of *Tetraclinis salicornioides* (Unger) Z. Kvaček (Pl. 1, fig. 1), an important member of Cupressaceae in the Neogene (Kvaček, 2007), is well documented by shoot fragments in the pre-evaporitic and evaporitic intervals, and by abundant shoots and cones in the post-evaporitic and Pliocene sites (Martinetto, 1999; Kovar-Eder et al., 2006). This species cannot be recognized in pollen records, where indistinct Cupressaceae are always reported and often reach high percentages.

Another interesting member of Cupressaceae, *Cupressus* cf. *sempervirens* L. (Pl. 1, fig. 5), is detected by means of abundant cones and shoots at Scipione Ponte (post-evaporitic Messinian). The relationships to the modern Mediterranean cypress is not yet precisely assessed, yet the requirements of the whole genus would indicate a plant adapted to sub-humid conditions, not cooler than warm-temperate (Farjon, 2005).

Among Pinaceae, mesotherm taxa (*Pinus* subgen. *Strobus* = *P. haploxylon* type and *Cathaya*) are fairly well represented, overall by pollen (Pl. 2, figs. 30, 33), and sometimes by macrofossils, especially during the Pliocene in the North (Martinetto, 2001). In the evaporitic Messinian, 5-clustered needles (typical of *Pinus* subgen. *Strobus*) are abundant, thus indicating that pines of this group grew in the lowland; the same can be said for the Zanclean, when cones assigned to the modern Balkanic species *Pinus peuce* Grieseb. occurred at several sites in NW Italy (Breolungi, Ca' Viettone, Sento, etc.).

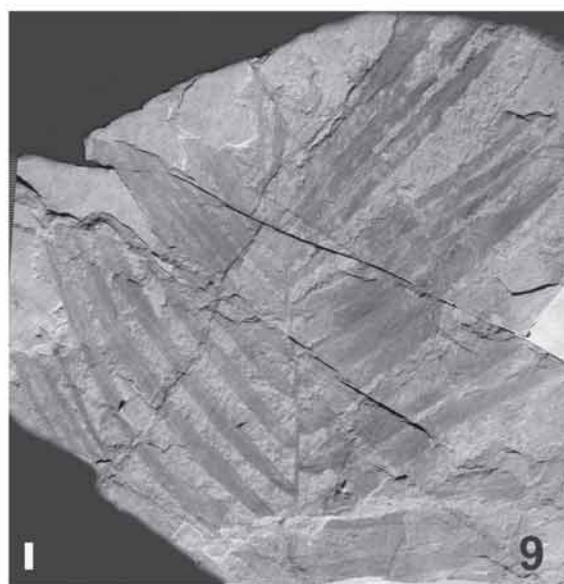
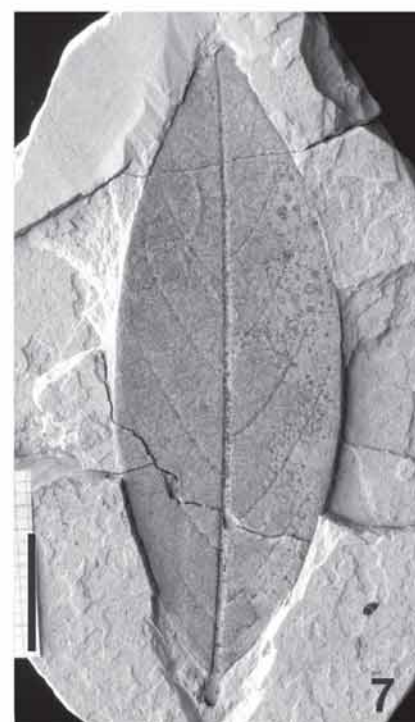
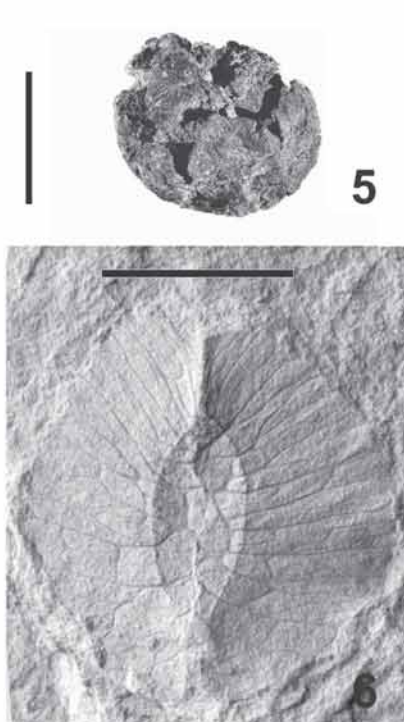
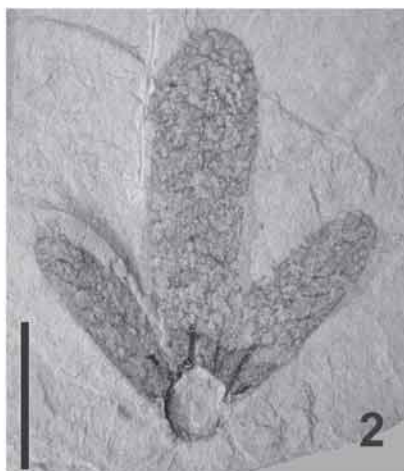
*Tsuga* (Pl. 2, fig. 35) and *Cedrus* (Pl. 2, figs. 31-32) always lack in the macrofossil record and are often frequent in pollen spectra, thus suggesting they would have occupied some upland niches away from any depositional basin. Needles of the *Tsuga*/*Pseudotsuga* type are common in the evaporitic Messinian (Guglielmetto & Iguera, 1994), but the identification of *Tsuga* remains is not well assessed, and only *Pseudotsuga*

#### EXPLANATION OF PLATE I

- fig. 1 - *Tetraclinis salicornioides* (Unger) Z. Kvaček. Moncucco Torinese, pre-evaporitic Messinian, shoot compression stored in the collection of the Museo di Geologia e Paleontologia dell'Università di Torino, PU105513.
- fig. 2 - *Engelhardia* (*Palaeocarya*) *macroptera* (Brongniart) Jaehnicen, Friedrich et Takáč; Borgo Tossignano, evaporitic Messinian, cycles XII-XIV (Vai, 1997), trilobate bract with fruit impression stored in the collections of the Museo Civico di Scienze Naturali di Faenza.
- fig. 3 - *Vitex* sp. (aff. *Vitex agnus-castus* L.), Sioneri, post-evaporitic Messinian (p-ev<sub>2</sub>), leaf impression stored in the collection of the Museo Civico Eusebio of Alba, Si.0024.
- fig. 4 - *Podocarpium podocarpum* (Al. Braun in Buckland) Herendeen; Sioneri, post-evaporitic Messinian (p-ev<sub>2</sub>), leaf impression stored in the collection of the Museo Civico Eusebio of Alba, Si.0040.
- fig. 5 - *Cupressus* cf. *sempervirens* L.; Scipione Ponte, post-evaporitic Messinian (p-ev<sub>2</sub>), weakly coalified cone stored in the collection of the Museo di Geologia e Paleontologia dell'Università di Torino, PU105514.
- fig. 6 - *Craigia brononii* (Unger) Z. Kvaček, Bužek et Manchester; Scaparoni, evaporitic Messinian, mericarp impression (inner side) stored in the collection of the Museo Civico Eusebio of Alba.
- fig. 7 - *Trigonobalanopsis rhamnoides* (Rossmassler) Z. Kvaček et Walther; Scaparoni, evaporitic Messinian, leaf impression stored in the collection of the Museo Civico Eusebio of Alba, Sc.0357.
- fig. 8 - *Platanus leucophylla* (Unger) Knobloch; Borgo Tossignano, evaporitic Messinian, cycles XII-XIV (Vai, 1997), leaf compression stored in the collections of the Museo Civico di Scienze Naturali di Faenza.
- fig. 9 - cf. *Calamus*; Palena, pre-evaporitic Messinian, leaf impression stored at Museo Paleontologico “Alto Aventino” of Palena.

Scale bars = 1 cm.







is reliably documented by cones in late Zanclean sites (Ca' Viettone: unpubl. data). *Picea* and *Abies* (Pl. 2, fig. 34), interpreted as temperate to cold temperate taxa requiring more or less year-long humid conditions, are always present in the pollen record, but lack in the macrofossil one. Again, upland niches are the probable explanation (Fig. 2), in agreement with the usual interpretation in pollen diagrams as "montane or high altitudinal" taxa (e.g. Bertini, 1992, 2006; Fauquette et al., 1998a, b; Suc et al., 1999).

Angiosperms are always abundant and diversified, and just a few taxa will be discussed here because of particular ecological, stratigraphic or taphonomical aspects. Concerning Lauraceae, we can confirm that the lack in pollen diagrams is often simply due to a taphonomic bias (see above), since Lauraceae is well documented by leaves and fruits. Leaves were reported in large variety and abundance by all the 19<sup>th</sup> and 20<sup>th</sup> century works on Messinian leaf assemblages (e.g.: Massalongo & Scarabelli, 1859; Brambilla, 1995), which would need to be updated by means of cuticular analysis. Up to now this technique has been only applied to a few specimens from Borgo Tossignano (Knobloch & Gregor, 1997), Torre Sterpi (Sachse, 2001) and the Alba area (unpublished data by Cilia & Martinetto). Yet, cuticular analysis was extensively applied to the Zanclean assemblage of Fossano (Fig. 1, Tab. 1), where the same leaf morphotypes occurring in Messinian evaporitic layers have been assigned to four Lauraceae species (Martinetto et al.,

2007a); one more species, *Cinnamomum costatum* (Mai) Pinggen, Ferguson & Collinson, was represented by fruits. Lauraceae remains are very scanty in p-ev<sub>2</sub> sediments: only very rare fruits of *Litsea sonntagii* Gregor occurred at Sioneri-Ciabot Cagna (Kovar-Eder et al., 2006). Overall, Neogene members of Lauraceae in Europe are interpreted as "subtropical" evergreen woody plants, even tall trees.

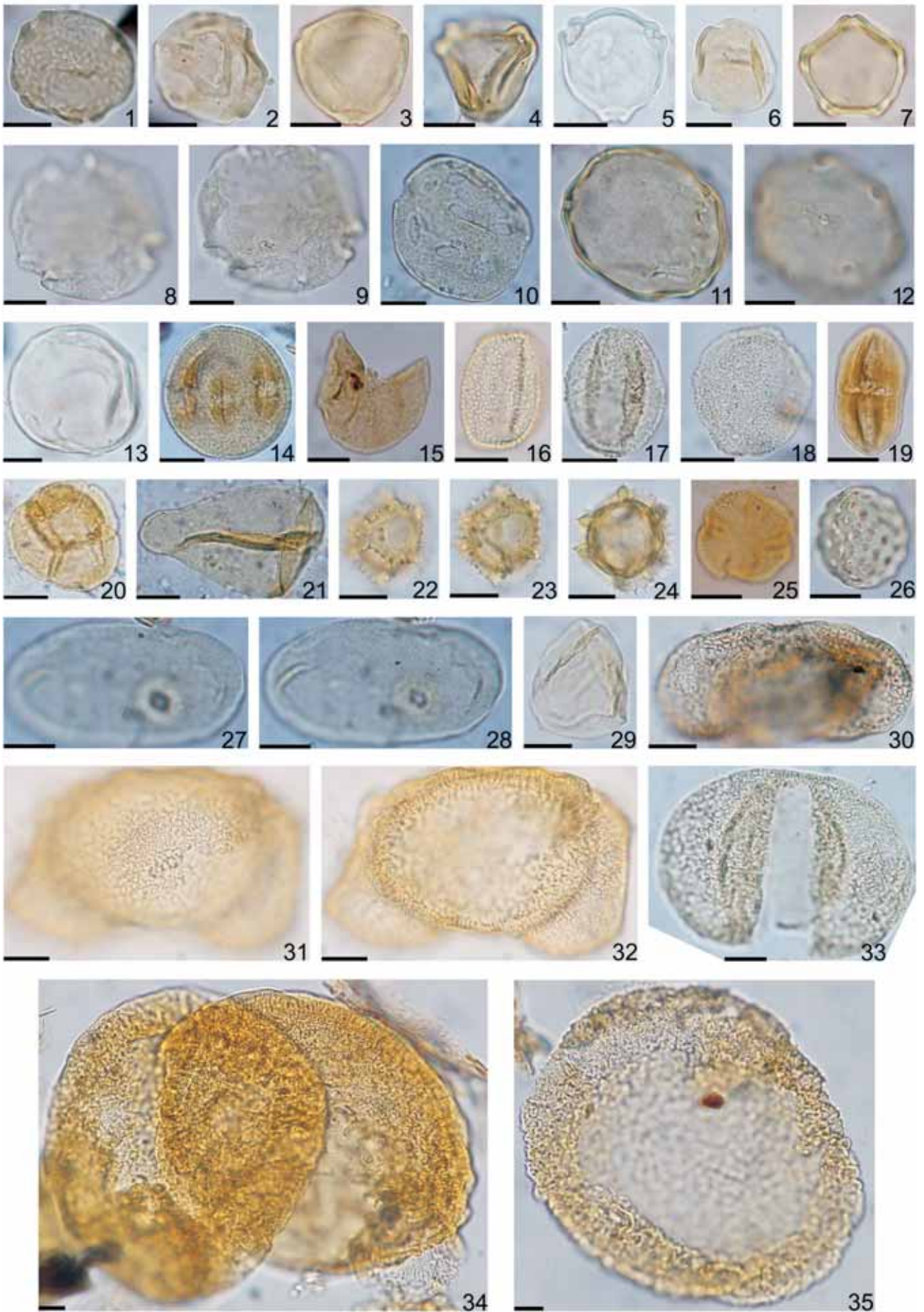
This same habit is reconstructed for *Trigonobalanopsis* (Pl. 1, fig. 7), an extinct member of Fagaceae (Kvaček, 2007) that is particularly common, and easily identified by means of carpological remains, in Zanclean assemblages (Basilici et al., 1997; Martinetto, 1999). Its abundance in the evaporitic Messinian is testified by leaves, which, however, are hardly identified without cuticular analysis. Tricolporate pollen grains close to those of the *Trigonobalanoids* group are very scanty and represented by taxa dubitatively attributed to the genus *Trigonobalanus* (e.g. Bertoldi et al., 1994), which was morphologically firstly described and discussed by Erdtman (1967) and later by Walther & Zetter (1993).

*Engelhardia* s.l. (Juglandaceae) is common in pollen records (e.g. Bertini, 2006; Fauquette et al., 2006; Pl. 2, fig. 6), and fruits were reported from the evaporitic Messinian (Pl. 1, fig. 2) and the Zanclean (Martinetto, 1999). After fruit morphology, the Neogene form of *Engelhardia* s.l. commonly found in Central and Southern Europe belongs to the independent section (or a fossil

## EXPLANATION OF PLATE 2

- fig. 1 - cf. *Zelkova* (Ulmaceae), Velona, pre-evaporitic Messinian.
- fig. 2 - *Juglans* (Juglandaceae), Maccarone, post-evaporitic Messinian.
- fig. 3 - *Corylus* (Betulaceae), Scaparoni, evaporitic Messinian.
- fig. 4 - *Rhoiptelea* (Rhoipteleaceae), Velona, pre-evaporitic Messinian.
- fig. 5 - *Betula* (Betulaceae), Scaparoni, evaporitic Messinian.
- fig. 6 - *Engelhardia* (Juglandaceae), Velona, pre-evaporitic Messinian.
- fig. 7 - *Alnus* (Betulaceae), Scaparoni, evaporitic Messinian.
- figs. 8-9 - Sca\_Ind. 01, Scaparoni, evaporitic Messinian.
- fig. 10 - *Liquidambar* (Altingiaceae), Velona, pre-evaporitic Messinian.
- figs. 11-12 - *Juglans* (Juglandaceae), Scaparoni, evaporitic Messinian.
- fig. 13 - *Carya* (Juglandaceae), Scaparoni, evaporitic Messinian.
- fig. 14 - *Fagus* (Fagaceae), Velona, pre-evaporitic Messinian.
- fig. 15 - *Taxodium/Glyptostrobus* type (Taxodiaceae), Scaparoni, evaporitic Messinian.
- fig. 16 - cf. *Fraxinus*, Scaparoni, evaporitic Messinian.
- fig. 17 - *Quercus* (Fagaceae), Velona, pre-evaporitic Messinian.
- fig. 18 - *Buxus* (Buxaceae), Velona, pre-evaporitic Messinian.
- fig. 19 - Apiaceae, Velona, pre-evaporitic Messinian.
- fig. 20 - Ericaceae, Velona, pre-evaporitic Messinian.
- fig. 21 - Cyperaceae, Velona, pre-evaporitic Messinian.
- figs. 22-24 - Asteraceae Cichorioideae, Scaparoni, evaporitic Messinian.
- fig. 25 - Rubiaceae, Velona, pre-evaporitic Messinian.
- fig. 26 - Chenopodiaceae, Velona, pre-evaporitic Messinian.
- figs. 27-28 - *Lygeum* (Poaceae), Velona, pre-evaporitic Messinian.
- fig. 29 - Poaceae, Maccarone, post-evaporitic Messinian.
- fig. 30 - cf. *Cathaya* (Pinaceae), Velona, pre-evaporitic Messinian.
- figs. 31-32 - *Cedrus* (Pinaceae), Scaparoni, evaporitic Messinian.
- fig. 33 - cf. *Pinus haploxylon* type (Pinaceae), Velona, pre-evaporitic Messinian.
- fig. 34 - *Abies* (Pinaceae), Velona, pre-evaporitic Messinian.
- fig. 35 - *Tsuga* (Pinaceae), Velona, pre-evaporitic Messinian.

Scale bars = 10 µm.





genus) *Palaeocarya* (Knobloch & Kvaček, 1976; Manchester, 1987). These ancient plants are reconstructed as semi-evergreen or summer-green trees growing under “subtropical” to warm-temperate conditions (Kvaček, 2007). Such ecological and climatic interpretations are in agreement with pollen records too (e.g. Fauquette et al., 1998b; Suc et al., 1999; Bertini, 2006).

*Myrica* (Myricaceae) and *Nyssa* (Nyssaceae), commonly represented in pollen records from the northern areas, are interpreted as “subtropical” and warm temperate deciduous woody plants, living under year-long humid edaphic conditions, possibly together with *Taxodium* and *Glyptostrobus* (therefore sometimes included in the informal “Taxodiaceae group”, e.g. Bertini, 1992; Bertoldi et al., 1994).

Other deciduous arboreal Angiosperms, typical of warm-temperate and temperate climates, are commonly represented by pollen and leaves within Messinian sediments (e.g. *Zelkova*, *Carya*, *Quercus*, and *Ulmus*; Pl. 2, figs. 1, 13, 17), and pollen grains are regular components of Zanclean assemblages, too. *Fagus* leaves are very common in the evaporitic Messinian (Martinetto et al., 2000), while no macrofossils are known in the post-evaporitic sediments, and occur again above, in the late Zanclean (fruits at Ca’ Viettone: Bertoldi & Martinetto, 1996). *Fagus* pollen grains (Pl. 2, fig. 14) were found, though never abundant, in both Messinian and Zanclean sediments. *Platanus leucophylla* (Unger) Knobloch (Platanaceae) leaves (Pl. 1, fig. 8) occur frequently in the evaporitic Messinian, while pollen is often scanty, which would suggest a restricted distribution of this tall deciduous tree in the riparian belts, in analogy with the situation detected in other Miocene basins (Knobloch, 1969).

*Craigia bronnii* (Unger) Z. Kvaček, Bužek & Manchester, a member of Malvaceae s. l. (Kvaček, 2004), has been interpreted as a deciduous tree that grew in warm-temperate forests (Kvaček, 2007). It occurs with several fruits in the evaporitic Messinian (Pl. 1, fig. 6), and is also documented (Martinetto, 2001) later in the Pliocene (Ca’ Viettone, late Zanclean according to Bertoldi & Martinetto, 1996). Two modern species, *C. yunnanensis* W.W. Smith & W.E. Evans and *C. kwangsiensis* Hsue, live under subtropical climate on East Asian uplands (1400-1700 m alt.). The climatic requirements of several accompanying plants in fossil assemblages indicate that the European Neogene species (*C. bronnii*) tolerated cooler conditions in comparison to the modern Asian species. Its pollen is probably sometimes misidentified as *Tilia*, a genus that does not seem having been common, since the macrofossil record is only represented by a few problematic leaves in the evaporitic Messinian (Martinetto et al., 2000), and no fruits.

The evergreen taxa with putative Mediterranean affinity (Kvaček et al., 2002), characteristic of regions with mild wet winters and pronounced summer droughts (e.g. *Quercus ilex-coccifera* type, *Olea*, *Ceratonia*, *Pistacia*, and *Phillyrea*) are better represented by pollen floras of the southern sites. Also *Cercis virgiliana* Massalongo (Fabaceae), documented by leaves at Gabbro I (Berger, 1958), seems to be a southern element, since it was

elsewhere recorded only at Senigallia and “Ancona”, either in the early or “mid” Messinian. The occurrence of *Olea moldavica* Negru (Oleaceae), in association with many “humid” elements, at Fossano suggests that *Olea*, usually considered a Mediterranean xerophyte in Italian Neogene pollen diagrams (e.g. Suc & Bessais, 1990; Suc et al., 1995a, b; Bertini, 2002), could also have another ecological meaning, i.e. as a subordinate element of the humid warm temperate forests. In post-evaporitic sediments (Torre Sterpi), Oleaceae are also documented by leaves of *Oleinites liguricus* Sachse, whose ecological meaning is not yet precisely defined (Sachse, 2001).

Three other angiosperms deserve a short mention as possible indicators of seasonally dry climate. The extinct legume *Podocarpium podocarpum* (Al. Braun in Buckland) Herendeen (Fabaceae) is a common element of Miocene floras of Central Europe (Herendeen, 1992), and occurs in abundance in the post-evaporitic of Sioneri (Pl. 1, fig. 4), in association with *Vitex* (Pl. 1, fig. 3), a genus of Verbenaceae comprising a shrubby species growing in Mediterranean dry river beds (*V. agnus-castus* L.). *Medicago* (Fabaceae), which occurs with fruits in the post-evaporitic site of Scipione Ponte, is a genus of herbs and shrubs prevalently distributed in dry to semi-humid Mediterranean environments.

Herbaceous Angiosperms (e.g. Asteraceae: Pl. 2, figs. 22-24, Poaceae: Pl. 2, figs. 27-29, Chenopodiaceae: Pl. 2, fig. 26) are often represented by many taxa in pollen records, rather scanty in the carpological record and absent in the leaf one (reed-like plants excepted). In this case we believe that the pollen record is crucial in assessing the real extent of the herbaceous cover, while the macrofossil one is strongly biased by taphonomical processes. In the Messinian post-evaporitic succession of Maccarone, the p-ev<sub>1</sub> herbaceous formations are marked by the occurrence (between ca 5.5. and 5.4 Ma) of *Lygeum* (Poaceae; Pl. 2, figs. 27-28), a typical steppic element of southern Mediterranean grasslands, which is virtually absent or very scanty in both the underlying (Vena del Gesso Fm.) and overlying (p-ev<sub>2</sub> and Argille Azzurre) deposits. *Lygeum* is almost lacking in the other post-evaporitic deposits of Central and Northern Italy: Trave (Marches); Cava Serredi (Tuscany); Scipione Ponte-Stirone (Emilia) and Sioneri (Piedmont). On the other hand, in Southern Italy *Lygeum* is common, as testified by the Neogene Sicilian pollen records (Suc & Bessais, 1990; Suc et al., 1995c; Bertini et al., 1998).

#### Vegetation - general features

Palaeobotanical data are particularly meaningful to reconstruct vegetation and biomes of the Mediterranean basin during Messinian and Pliocene. Nevertheless, both pollen and macrofossil-based reconstructions have been often affected by the use of an heterogeneous nomenclature (e.g.: Mai, 1995; Suc et al., 1995a, b, 1999; Martinetto, 1996, 1999; Palamarev & Ivanov, 1998; Bertini, 2002; Fauquette et al., 2006; Kovar-Eder et al., 2006; Favre et al., 2007), sometimes adopting an admixture of biome and vegetation types with unclear synecological definitions, such as “subtropical evergreen forests including *Engelhardia*, Altingiaceae,



Taxodiaceae with some tropical elements (Euphorbiaceae, Mimosaceae)” (Favre et al., 2007). Indeed, a summarizing work pointing to a concise, accurate and revised classification of Cenozoic vegetation would be badly needed. In this paper we adopt informal biome/vegetation units known as “formation classes”, which had been used by Bertini (2002) and largely coincide with those proposed and developed by many other palynologists (e.g. Suc et al., 1995a, b, 1999). Based on the pollen flora, five principal “formation classes” (Tab. 2) have been described for the Neogene of Italy, whose spatial and temporal distribution was related to changes of both climate and topography, induced by tectonics and eustatism (Bertini, 2002). For biome reconstructions, Fauquette et al. (1999) developed an innovative approach using the typology established by Prentice et al. (1992), CAM climatic estimations and the vegetation description based on pollen data. They calculated Pliocene and modern climate anomalies, interpolated on the Leemans & Cramer (1991) grid to obtain Pliocene climate. According to these results, and using the scheme of the “Biome 1” model (Prentice et al., 1992), 12 biomes were reconstructed around the Mediterranean area (see Fig. 11 in Fauquette et al., 1999). Yet, only three biomes were described for the period 5.32 to 5 Ma: (A) broad-leaved evergreen/warm mixed forest resembling

modern types found today in eastern China or in California; (B) xerophytic woods/scrub (dominance of tall xerophytic plants), C) warm grassland/scrub. Biomes (A) and (C) are represented by sites in close proximity, e.g. between Tarragona and Barcelona (e.g. Fauquette et al., 1999; Suc et al., 1999). The palaeofloral reconstructions obtained for Central and Northern Italy sites indicate that only biome (A) “broad-leaved evergreen/warm mixed forest” is definitely represented, as the climatic reconstruction shows a homogeneous climate for this whole part of Italy.

Further distinctions of zonal vegetation types within biome (A) are necessarily based on the reconstructed floristic composition. Mai (1995) provided a complete overview of vegetation types reported for the Cenozoic of Europe (with a macrofossil bias), and attempted to achieve a uniform nomenclature. As for warm temperate evergreen/mixed forests he discerned two types: “Warmgemässige immergrüne Laubwälder” (European Neogene “Warm Temperate Evergreen Broad-leaved Forests”), with more abundant evergreen trees, and “Gemischte mesophytische Wälder” (European Neogene Mixed Mesophytic Forests), with a mixture of deciduous and evergreen trees (“up to 50%”). Both of them are characterized by a high floristic similarity with modern East Asian forests, and their discrimination, which is not straightforward and beyond the aim of this paper,

«Formation classes»	Characteristic floral elements	Description
1. “Subtropical” humid forest	<i>Taxodium</i> / <i>Glyptostrobus</i> type, <i>Nyssa</i> , <i>Myrica</i> , <i>Ampelopsis</i> , <i>Arecaceae</i> , <i>Clethraceae</i> , <i>Cyrillaceae</i> , <i>Distylium</i> , <i>Engelhardia</i> , <i>Eurya</i> , <i>Lauraceae</i> , <i>Magnolia</i> p.p., <i>Sapotaceae</i> , <i>Sciadopitys</i> , <i>Sequoia</i> , <i>Symplocos</i> , <i>Toddalia</i> , <i>Trigonobalanopsis</i> , <i>Visnea</i> , etc.	Mega-mesothermic trees living under a climatic regime with a small range of temperature and abundant and well distributed rainfall throughout the year (humid “subtropical” climate).
2. Temperate broad-leaved deciduous forest	<i>Quercus</i> , <i>Carya</i> , <i>Carpinus</i> , <i>Ulmus</i> , <i>Zelkova</i> , <i>Tilia</i> , <i>Acer</i> , <i>Pterocarya</i> , <i>Juglans</i> , <i>Fraxinus</i> , <i>Buxus</i> , <i>Liquidambar</i> , <i>Parrotia</i> , <i>Castanea</i> , <i>Celtis</i> , etc.	Mesothermic trees living under a climatic regime with adequate precipitation in all months; they withstand a strong annual temperature cycle with a cold winter season and a warm summer season (warmer continental and humid “subtropical” climates).
3. Sclerophyll forest	<i>Quercus ilex</i> type, <i>Phillyrea</i> , <i>Olea</i> , <i>Pistacia</i> , <i>Cupressus</i> , etc.	Xerophilous hard leaved trees and shrubs, which are typical of regions with a wet winter and dry summer (Mediterranean climate).
4. Mid to high elevation forest	<i>Tsuga</i> , <i>Cedrus</i> , <i>Abies</i> , <i>Picea</i> . Broad-leaved deciduous trees and shrubs ( <i>Fagus</i> p.p. and <i>Betula</i> ) can be members of the early successional stages.	Mesothermic (e.g. <i>Tsuga</i> and <i>Cedrus</i> ) and microthermic gymnosperms ( <i>Abies</i> and <i>Picea</i> ) which demand humidity. The latter are dominant plants in the modern boreal forest, corresponding to subarctic and cold continental climates characterized by cold summer and long winter with yearlong humid conditions. This forest extends into lower latitude wherever mountains chains are present.
5. Open vegetation (grasslands)	<i>Asteraceae</i> , <i>Poaceae</i> , <i>Chenopodiaceae</i> , <i>Caryophyllaceae</i> , <i>Brassicaceae</i> , <i>Apiaceae</i> , <i>Cannabaceae</i> , <i>Knautia</i> , <i>Cistaceae</i> , <i>Convolvulaceae</i> , <i>Ericaceae</i> , <i>Euphorbiaceae</i> , <i>Ranunculaceae</i> , <i>Fabaceae</i> , etc.	Grasses and herbs which indicate dry climatic conditions (e.g., <i>Lygeum</i> ); it includes prevalently coastline vegetation.

Tab. 2 - Principal “formation classes” described for the Neogene of Italy (modified from Bertini, 2002).

requires a careful taphonomical interpretation of rich and diversified macrofloral records.

We just recall here that Martinetto (1996) reported these two zonal vegetation types for the late Zanclean of Northern Italy and suggested that some peculiar genera (*Cinnamomum*, *Eurya*, *Fagus*, *Hartia*, *Magnolia* and *Ternstroemia*) allowed tracing a parallelism between both types and some modern plant communities of the “subtropical vegetation zone” of China (Wang, 1961; Hou, 1983; Ying, 1983). In analogy with the Chinese model, a high-diversity closed forest community has been reconstructed, with a simultaneous cover of evergreen (*Cinnamomum*, *Distylium*, *Eurya*, *Ficus*, *Hartia*, *Magnolia* p.p., *Meliosma* subgen. *Meliosma*, *Symplocos*, *Ternstroemia*, *Trigonobalanopsis*, *Visnea*) and deciduous trees and shrubs (*Ehretia*, *Liquidambar*, *Liriodendron*, *Magnolia* p.p., *Mallotus*, *Nyssa*, *Engelhardia* (*Palaeocarya*), *Paulownia*, *Quercus*, *Rehderodendron*). Conifers have also been considered to contribute to the forest cover, especially *Cathaya*, *Chamaecyparis*, *Cryptomeria*, *Pinus* and *Tetraclinis*.

#### TERRESTRIAL VEGETATION AND CLIMATE RECONSTRUCTION

Palaeofloral data from Northern-Central Italy are here reconsidered for an updated synthesis of the Messinian to Zanclean terrestrial vegetation and climate. Vegetation is shown in sketchy cartoons that, however, point to faithfully reproduce the proportion of conifers, evergreen/and deciduous woody angiosperms, and herbs detected in each time slice (Fig. 2). In general, the long pollen records studied in Northern and Central Italy (e.g. Bertini, 2002, 2006) point to a long-lasting persistence of a “subtropical” climate, with well-known North to South gradients within the Mediterranean area, at least from the Messinian. Specific features of four principal intervals are reported below.

##### *Messinian pre-evaporitic times*

Leaves from the early Messinian assemblages prove the simultaneous occurrence of both deciduous and evergreen broad-leaved elements. The northern sites (Banengo, Roddi; Fig. 1) show a peculiar prevalence of leaves of deciduous Fagaceae (*Fagus* and *Quercus*), while the southern one of Palena shows more sclerophyllous types. Similarly, the evergreen oak *Quercus mediterranea* Unger is common at Gabbro I (Berger, 1958), while it is doubtful in the northern sites (even those of the evaporitic Messinian - Tab. 1). The best-known assemblage of Gabbro I points to a warm-temperate humid to sub-humid climate (Kovar-Eder et al., 2006), and the others do not provide contrasting evidence, excepted a clue for less humidity at Palena suggested by small leaf size and generalized sclerophylly. The pollen record from Velona (Tuscany; Ghetti et al., 2002) testifies a dominant “subtropical humid forest”, probably interfingering with a sparse “sclerophyll forest” (Tab. 2), both of them growing on well-drained soils of the areas surrounding wetlands where deposition took place. In distant sites, presumably westwards of the basin, “mid to high elevation forest” with meso- to

microtherm conifers expanded at different times. Quantitative climate analyses, i.e. the CA and the CAM (Bruch et al., 2002) support a stable, warm temperate and humid climate. According to the CAM, mean annual temperatures (MAT) were comprised between 15.6 and 19.8°C (most likely values, MLV, between 17.2 and 18.4°C); mean annual precipitation (MAP) was generally very high, with values from 1100 to 1300-1550 mm (MLV around 1200 mm).

Always in Central Italy but on the Adriatic side, the Trave early Messinian pollen record is also characterized by the elements of a “subtropical humid forest” testifying a prevalent warm and humid climate (Iaccarino et al., in press). Here, the large percentage values of *Pinus* were explained as a taphonomic bias frequent in marine settings (Heusser & Balsam, 1977).

##### *The Messinian evaporitic phase*

In the evaporite-bearing formations of Piedmont (Cherasco, Scaparoni and Sioneri evaporitic Messinian sections: Gaudant & Cavallo, 2008) and Vena del Gesso (Emilia-Romagna: Cava Li Monti and Borgo Tossignano sections; Bertini, 1992, 1994a, b, 2006; Fig. 1) basins pollen data allowed to reconstruct a typical lowland vegetation of “subtropical humid forest” type (Tab. 2), as indicated by the good representation of thermophilous arboreal plants. Upland taxa are fairly well represented only in a few intervals characterized by the increase in *Picea* and *Cedrus* pollen (cooler episodes). The presence of swamp areas adjacent to the emerging Apennine chain is suggested by the high frequency of pollen of the *Taxodium*/*Glyptostrobus* type and *Alnus* (Pl. 2, fig. 7). We have no evidence of an increase of salt marsh vegetation. Repeated expansions of the swamp vegetation or *Pinus* suggest variations in the water level (Heusser & Balsam, 1977). Herbs are poorly represented in North Italian sections, suggesting a dominant forested environment (Fig. 2) and the absence of severe dry conditions, in strong contrast with the southern records, where xeric conditions occurred before, during, and after the evaporitic phases (Suc & Bessais, 1990; Suc et al., 1995; Bertini et al., 1998). Also in Northern-Central Italy no major changes from moist to dry conditions appear to have occurred across the Salinity Crisis.

A clue to the uniformity of biomes and vegetation from North (Alba) to South (Ancona), during the evaporitic interval, is the occurrence of the same deciduous (e.g., *Acer*, *Alnus*, *Fagus*, *Liquidambar*, *Platanus*, *Populus*, *Pterocarya*, *Quercus* p.p., *Salix*, *Zelkova*) and evergreen (e.g., Lauraceae, *Engelhardia* (*Palaeocarya*) [semi-evergreen?], *Smilax*, *Trigonobalanopsis*) broad-leaved taxa associated to several conifers (*Tetraclinis*, *Taxodium*, *Sequoia*, *Pinus*). A few taxa have been exclusively detected in the northernmost localities (*Celtis trachytica* Unger, *Hedera* cf. *helix* L., *Parrotia pristina* Ettingshausen), while *Liriodendron procaccinii* Massalongo and *Sassafras ferretianum* Massalongo are restricted to the southernmost sites.

For the evaporitic Messinian both leaf physiognomy and taxonomic composition point to an arboreal vegetation rich in evergreen taxa growing under warm temperate and humid palaeoclimatic conditions (Gregor,

1990; Martinetto et al., 2000, 2007a). Evergreen taxa lack in two poor assemblages of Piedmont (Monticello, Piobesi, both near Alba), presumably for taphonomical reasons and not as a definite indication for a prevalently deciduous forest type (Martinetto et al., 2007a). Macrofossil data show that members of Lauraceae with evergreen coriaceous leaves were certainly common in the lowland vegetation of Northern Italy during the evaporitic Messinian (Fig. 2), while they show a retreat in the post-evaporitic times.

Climatic reconstructions for the evaporitic Messinian, obtained by analysing pollen data according to the CAM (Fauquette et al., 2006), suggest that climate was warm and humid with MAT between 15.5 and 19.8°C (MLV around 17 °C) and MAP around 1000 and 1300 mm (MLV around 1100-1200 mm). Such data are in agreement with those based on the physiognomic analysis of leaf assemblages (Martinetto et al., 2007a). Minor discrepancies emerge concerning the estimate of precipitations; in fact leaf analysis provides significantly higher values, probably due to a local microclimatic signal.

#### Messinian post-evaporitic times

Post-evaporitic conditions are marked by a significant expansion of the “subtropical” arboreal taxa in pollen diagrams, coincident with a peak of herbs, including the subdesertic *Lygeum* in the p-ev<sub>1</sub> portion of Maccarone (e.g. Bertini, 1992, 2006). The stratigraphic distribution, as well as the ecologic and climatic requirements of *Lygeum*, supports its northward expansion as a consequence of a drier phase close to 5.5 Ma. At a global scale, this phase matches with the first period of warming associated with sea-level rise and deep-water warming in phase with isotope stages TG11/TG9 (Vidal et al., 2002). It should be stressed that the “*Lygeum* drier phase” is successive to the deposition of both primary and resedimented evaporites and coincides p.p. to the hiatus involving the p-ev<sub>1</sub> deposits in the Vena del Gesso basin.

Short-term humidity fluctuations, indicated by the frequent opposition among the curves of herbs and “subtropical” arboreal taxa, have been detected; they are however much better expressed in the p-ev<sub>2</sub> sediments especially of the Trave section (Bertini et al., 2006; Iaccarino et al., in press). In the post-evaporitic Messinian succession of Maccarone, the increase of coniferous pollen grains (notably *Cedrus* with subordinate *Tsuga*, *Picea*, and *Abies*) and the disappearance of *Lygeum* have been evaluated not only in terms of climate variation, but also of depositional environmental change (Bertini, 2006; Fauquette et al., 2006).

For the sketchy reconstruction of post-evaporitic vegetation and climate (Fig. 2) pollen data have been integrated with the macrofloral information provided by the two post-evaporitic (p-ev<sub>2</sub>) macrofossil assemblages of Scipione Ponte-Stirone and Sioneri-Ciabot Cagna. These contain a rich assemblage of woody and herbaceous plants indicating a warm-temperate climate, yet the evaluation of humidity conditions is not easy. Some of the woody plant genera (*Cyclea*, *Litsea*, *Magnolia*) occur today only in humid forests, however, it is not too hazardous to imagine that in latest Messinian

palaeoenvironments they could find a suitable ecological niche in some sort of forests concentrated along rivers (Kovar-Eder et al., 2006). On well-drained soils a sub-humid, more open forest was probably developed. In fact the humidity-requiring *Fagus*, so common in pre-evaporitic/evaporitic Messinian and Pliocene assemblages, as far as we know lacks from the post-evaporitic deposits (rare pollen excepted). Noteworthy is also the rarity of Lauraceae (see above) and the absence in the p-ev<sub>2</sub> macrofossil record of the “humid” *Symplocos* (Mai & Martinetto, 2006) and *Trigonobalanopsis* (Kvaček, 2007), in contrast to their common occurrence in Zanclean floras (Martinetto, 1999; Mai & Martinetto, 2006). In the post-evaporitic Messinian succession of Maccarone only scanty pollen grains of *Symplocos* have been recorded.

Additional clues for a relatively low humidity in p-ev<sub>2</sub> are the abundance of *Cupressus* cf. *sempervirens* L. (cones and shoots at Scipione Ponte) and the occurrence of *Medicago* (fruits at Scipione Ponte) and *Vitex* (leaves at Sioneri-Ciabot Cagna: Pl. 1, fig. 3). Also the abundance of the legume *Podocarpium podocarpum* (Al. Braun in Buckland) Herendeen at Sioneri-Ciabot Cagna may be due to peculiar environmental conditions, since this species is very rare in the evaporitic Messinian and never occurs in the many Pliocene floras of the same region.

For the post-evaporitic interval CAM reconstructions are available for Maccarone (Fauquette et al., 2006: ca 5.5 Ma to 5.3 Ma), where MAT is evaluated between 16 and 20°C for most spectra, but up to 23-24.5°C for a few others, with most likely values oscillating between 17 and 20°C (only one spectrum shows a lower MLV around 15°C). MAP is less stable along the succession. The first part of the sequence is characterized by large intervals, from around 400 to 1300 mm - MLV 1100 mm -, and smaller intervals from 1100 to 1300 mm, whereas the second part of the Messinian is characterised by more precise ranges from 700 to 1300 mm with MLV around 800 to 1200 mm.

#### Zanclean

The Messinian-Zanclean transition is well documented by pollen (e.g. Bertini, 2006). On the other hand, macrofossil data are almost completely lacking from 5.3 to 4.0 Ma. Pollen floras of the Zanclean are very similar to the Messinian post-evaporitic ones, while the late Zanclean macrofloras of Pocapaglia and related sites contain some “exotic” genera which are not recorded in Messinian sites: *Aralia*, *Mahonia*, *Meliosma*, *Cephalotaxus*, *Actinidia*, *Eurya* s.s., *Hartia*, *Mallotus*, *Paulownia*, *Phellodendron*, *Rehderodendron*, *Sabia*, *Sinomenium*, *Tetrastigma*. This could indeed be a sign of floral change, but one should also consider that the foregoing taxa are easily detected only by means of carpological analyses, and the carpological record is richer in the Pliocene than in the Messinian, thus suggesting a possible bias.

In the marine sections of Northern and Central Italy, the Zanclean pollen record (e.g. Castello D’Appio and Cava di Villanova: Zheng, 1990; Stirone; Monticino ‘87; Maccarone: Bertini, 1992, 1994, 2001) suggests relatively stable climatic conditions, characterized by



the development of a forest vegetation typical of a humid warm-temperate climate (Fig. 2). Nevertheless, the slight contrast of mega-mesotherm elements (e.g. *Engelhardia*, *Taxodium/Glyptostrobus* type) and meso-microthermic ones (*Cedrus*, *Tsuga*, *Picea*, *Abies*) suggests moderate temperature fluctuations. The co-occurrence of *Picea* with *Abies* and *Betula* (Pl. 2, fig. 5), suggests the presence of distally-located montane areas (e.g. at Stirone to the North in the Alps and their foothills).

Swamps are documented by the consistent percentage of pollen of the *Taxodium/Glyptostrobus* type, followed by *Nyssa*, *Alnus*, and *Cephalanthus*. Other possible swamp elements are: Arecaceae, *Magnolia*, Clethraceae, Cyrillaceae. *Salix* and *Populus* are better regarded as riparian elements. In the coastal areas psammophile or halophyte vegetation was very limited.

Towards the hinterland, sparse thermophilous evergreen elements such as *Olea*, *Phillyrea* were present, probably within the dominant “subtropical humid forest”, representing the regional Zanclean vegetation in Northern Italy. The composition of this forest is particularly well documented in continental deposits studied in Piedmont (e.g. Ca’ Viettone: Allason et al., 1981; Bertoldi & Martinetto, 1996), Liguria (e.g. Sarzana: Bertoldi et al., 1994) and Tuscany (e.g. Aulla and Vallescura: Bertoldi, 1988), where pollen of *Reevesia*, *Itea*, *Symplocos*, Clethraceae/Cyrillaceae, Sapotaceae, *Magnolia* and cf. *Trigonobalanus* is fairly more frequent than in marine sediments. This regional Zanclean vegetation of Northern Italy has been compared (Martinetto, 1996; Kovar Eder et al., 2006) on a floral basis to the cooler types of forests in the modern “subtropical vegetation zone” of East Asia (Hou, 1983), and the recent Asian analogue allowed to reconstruct a warm-temperate humid climate with MAT 15–17°C, and MAP above 1000 mm per year (Wang, 1961; Hou, 1983; Satoo, 1983).

These results are in agreement with those obtained with the CAM applied to the Zanclean pollen record of Stirone, which confirm a climatically stable interval with some slight oscillations in temperature and precipitation (Bertini, 2001; Fauquette & Bertini, 2003). During this period MAT were between 16 and 20°C, with MLV around 17–19°C; MAP between 1100 and 1500–1600 mm, with MLV around 1200–1300 mm (Fauquette & Bertini, 2003). Similar climate conditions were also reconstructed for the Zanclean interval of Maccarone (Fauquette et al., 2006). The CAM results obtained for the late Zanclean portion of Stirone section (Fauquette & Bertini, 2003) are also in good agreement with the CA results of Fossano (Martinetto et al., 2007b), and the NLR method applied to the macrofloras of Ca’ Viettone, Pocapaglia, and Sento I (Basilici et al., 1997).

CAM showed that, during Zanclean, the climate in the North Mediterranean area was warmer and more humid than today (respectively +1–4°C and +400–700 mm) whereas in the South Mediterranean region, the climate was warmer and drier than today (e.g. Fauquette et al., 1999, 2006; Fauquette & Bertini, 2003). The North to South gradient for both temperatures and precipitation confirms the latitudinal gradient already pointed out by pollen data.

## CONCLUSIONS

Multiple palaeobotanical data sets (pollen, leaves, fruits and seeds) have been used to investigate floristic, vegetational and climatic changes as well as to reconstruct formation classes during the Messinian and Zanclean in Northern and Central Italy. Overall evidence indicates that humid conditions prevailed not only in the Zanclean but also in the Messinian. Precipitation was sufficiently high for the persistence of a “subtropical humid forest” from 6.0 to 3.5 Ma, nevertheless wetter/drier fluctuations, linked to astronomical precession, have been recorded especially in post-evaporitic deposits. The principal phases of reduced humidity were not synchronous to the deposition of gypsum, but occurred later, in both the p-ev<sub>1</sub> (see *Lygeum* phase close to 5.5 Ma) and p-ev<sub>2</sub> (from 5.4 to 5.33 Ma). The single pollen record provided by primary gypsum (Scaparoni, evaporitic Messinian, Piedmont) indicates a humid forest assemblage, similarly to all the other macro- and micropalaeobotanical records from marls and clays of the evaporitic Messinian, and this would suggest to reconsider the real extent of humidity variation in a complete Messinian cycle (e.g. Vai & Ricci Lucchi, 1977). Of course, we cannot provide direct palaeoclimatic evidence for the palaeobotanically barren primary gypsum beds (Vena del Gesso basin), however it is curious that for all the clastic sediments adjacent to such beds we can definitely reconstruct palaeofloras and vegetation types which are never connected to desertic or subdesertic conditions. We suggest that palaeoenvironmental models should better investigate the possibility that increases in salinity might have been caused by high evaporation in the South Mediterranean, while the water input to the Adriatic-Padane basin might have been constantly higher than evaporation. Such hypothesis is also supported by the comparison between the Northern and Southern pollen records, which reveals climatic gradients within the Mediterranean, as well as by the recent facies analyses on the Messinian evaporites from the Mediterranean area (Lugli et al., 2007). Finally our integrated study confirms previous palynological evidence (Bertini, 2006) proposing: 1. more complex climate scenarios than that predicting an overall aridity during the Messinian; 2. that the Messinian Salinity Crisis does not produce dramatic effects on Italian flora and vegetation, which suffer their major changes (e.g. prominent development of steppe) later, in coincidence with the phase of maximal expansion of the Arctic glaciation and the onset of glacial/interglacial cycles at 2.6 Ma.

## ACKNOWLEDGEMENTS

We are thankful to Oreste Cavallo and to Francesco Della Pierre for providing information, material, collaboration in field-work and indications on the stratigraphic framing of the Piedmont basin sites, as well as useful comments to the preliminary text; to Jean Gaudant for promoting pollen analyses on Piedmont successions, and for useful discussions on palaeoenvironmental problems; to Benedetta Lanini, who provided pollen data from some levels of the Sioneri and Scaparoni successions. Furthermore, the authors wish to acknowledge Paolo Costa and Marco Sami,

who facilitated the study of the Borgo Tossignano collections of the Museo Civico di Scienze Naturali, Faenza. Information and access to the Palena macrofossil collection has been kindly provided by Silvano Agostini and Maria Adelaide Rossi. Finally, we are grateful to Severine Fauquette and Vasilis Teodoridis for their useful suggestions and critical review of the manuscript.

## REFERENCES

- Allason B., Carraro F., Ghibaudo G., Paganelli A. & Ricci B. (1981). Prove palinologiche dell'età pleistocenica inferiore di depositi "villafranchiani" in Piemonte. *Geografia Fisica e Dinamica Quaternaria*, 4: 39-47.
- Basilici G., Martinetto E., Pavia G. & Violanti D. (1997). Paleoenvironmental evolution in the Pliocene marine-coastal succession of Val Chusella (Ivrea, NW Italy). *Bollettino della Società Paleontologica Italiana*, 36 (1-2): 23-52.
- Berger W. (1958). Untersuchungen an der obermiozänen (sarmatischen) Flora von Gabbro (Monti Livornesi) in der Toskana. *Palaeontographia Italica*, 51: 1-96.
- Bertini A. (1992). Palinologia ed aspetti ambientali del versante adriatico dell'Appennino centro-settentrionale durante il Messiniano e lo Zancleano. Unpublished PhD Thesis, 88 pp., University of Modena, Italy.
- Bertini A. (1994a). Messinian-Zanclean vegetation and climate in North-Central Italy. *Historical Biology*, 9: 3-10.
- Bertini A. (1994b). Palynological investigations on Upper Neogene and Lower Pleistocene sections in central and northern Italy. *Memorie della Società Geologica Italiana*, 48: 431-443.
- Bertini A. (2001). Pliocene climatic cycles and altitudinal forest development from 2.7 Ma in the Northern Apennines (Italy): evidence from the pollen record of the Stirone section (~5.1 to ~2.2 Ma). *Géobios*, 34 (3): 253-265.
- Bertini A. (2002). Palynological evidence of upper Neogene environments in Italy. *Acta Universitatis Carolinae-Geologica*, 46: 15-25.
- Bertini A. (2006). The Northern Apennines palynological record as a contribute for the reconstruction of the Messinian palaeoenvironments. *Sedimentary Geology*, 188/189: 235-258.
- Bertini A., Londeix L., Maniscalco R., di Stefano A., Suc J.P., Clauzon G., Gautier F. & Grasso M. (1998). Paleobiological evidence of depositional conditions in the Salt Member, Gessoso-Solfifera Formation (Messinian, Upper Miocene) of Sicily. *Micropaleontology*, 44 (4): 413-433.
- Bertini A., Ricci-Lucchi M., Gennari R. & Manzi V. (2006). The Trave section (Ancona, Italy): palynological evidence from the Messinian post-evaporitic deposits. RCMNS, Parma, 2006. Abstract: A.08.
- Bertoldi R. (1988). Una sequenza palinologica di età Rusciniense nei sedimenti lacustri basali del bacino di Aulla-Olivola (Val di Magra). *Rivista Italiana di Paleontologia e Stratigrafia*, 94 (1): 105-138.
- Bertoldi R. & Martinetto E. (1996). Ricerche paleobotaniche (palinologiche e paleocarpologiche) sulla successione "villafranchiana" del Rio Ca' Viettone. *Il Quaternario*, 8 (2): 403-422.
- Bertoldi R., Binotti A. & Castello F. (1994). *Reevesia* and *Itea* in the pollen flora of the Upper Neogene continental deposit at Sarzana (lower Magra valley, Northern Italy). *Review of Palaeobotany and Palynology*, 80 (1/2): 159-172.
- Brambilla G. (1992a). Prime considerazioni cronologico-ambientali sulle filliti del Miocene superiore di Portalbera (Pavia-Italia settentrionale). In Pearce M., Nuove ricerche archeologiche in provincia di Pavia. Civico Museo Archeologico di Casteggio e dell'Oltrepò Pavese, pp. 109-113.
- Brambilla G. (1992b). Le filliti plioceniche del Canton Ticino nelle collezioni del Museo Cantonale di Storia Naturale di Lugano: considerazioni sistematiche, cronologiche ed ambientali. *Bollettino della Società Ticinese di Scienze Naturali*, 80 (2): 63-95.
- Brambilla G. (1995). La flora fossile del Senigalliese: dati per la ricostruzione dell'ambiente nel Miocene superiore. In Pacciarelli M. & Vai G.B., Musei Civici di Imola: La collezione Scarabelli. I - Geologia. Musei Civici di Imola, Imola, pp. 240-261.
- Brambilla G. & Gallo M. (2002). Analisi stratigrafica e paleobotanica della successione messiniana di Bric Santa Margherita (Nizza Monferrato, Asti, Italia NW). *Bollettino del Museo Regionale di Scienze Naturali di Torino*, 19 (1): 191-283.
- Brambilla G., Ronchetti G. & Vittadini Zorzoli M. (1982). Semi e filliti delle argille messiniane (Miocene superiore) di Carbonara Scrivia (Alessandria). *Atti dell'Istituto Botanico e del Laboratorio Crittogamico di Pavia*, 1: 31-40.
- Bruch A., Fauquette S. & Bertini A. (2002). Quantitative climate reconstructions on Miocene palynofloras of the Velona, pre-evaporitic Messinian Basin (Tuscany, Italy). *Acta Universitatis Carolinae-Geologica*, 46 (4): 27-37.
- Butler W.H., Likhovich W.H., Grasso M., Pedley H.M. & Ramberti L. (1995). Tectonics and sequence stratigraphy in Messinian basins, Sicily: constraints on the initiation and termination of the Mediterranean salinity crisis. *Geological Society of American Bulletin*, 107: 425-439.
- Cavallo O. & Martinetto E. (1996). Flore plioceniche del bacino del Tanaro. *Alba Pompeia*, 17 (1): 5-31.
- Cavallo O., Pavia G. & Macagno M. (1986). Fossili dell'Albese: aspetti geologici e paleontologici delle Langhe e del Roero. 217 pp. Famija albeisa, Alba.
- Clauzon G., Suc J.P., Gautier F., Berger A. & Loutre M.F. (1996). Alternate interpretation of the Messinian salinity crisis: controversy resolved? *Geology*, 24: 363-366.
- Clauzon G., Suc J.P., Popescu S.M., Marunteanu M., Rubino J.L., Marinescu F. & Melinte M.C. (2005). Influence of Mediterranean sea-level changes on the Dacic Basin (Eastern Paratethys) during the late Neogene: the Mediterranean Lago Mare facies deciphered. *Basin Research*, 17: 437-462.
- Collinson M.E. (1986). Use of modern generic names for plant fossils. In Spicer R.A. & Thomas B.A. (eds.), Systematic and Taxonomic Approaches in Palaeobotany. Systematic Association Spec. Vol. 31, 92-104, Clarendon Press, Oxford.
- Corselli C. & Grecchi G. (1984). The passage from hypersaline to hyposaline conditions in the Mediterranean Messinian: discussion of the possible mechanisms triggering the "Lago-Mare" facies. *Paléobiologie Continentale*, 14: 225-239.
- Erdtman G. (1967). On the pollen morphology of *Trigonobalanus* (Fagaceae). *Botaniska Notiser*, 120: 324-333.
- Falorni M. (1988-89). La flora messiniana di Villa Nardi (LI) e le sue implicazioni paleoambientali. Considerazioni sistematiche relative al genere *Pinus*. Unpublished graduation thesis, 229 pp. University of Pisa.
- Farjon A. (2005). A monograph of Cupressaceae and *Sciadopitys*. 650 pp. Royal Botanic Gardens, Kew.
- Fauquette S. & Bertini A. (2003). Quantification of the northern Italy Pliocene climate from pollen data: evidence for a very peculiar climate pattern. *Boreas*, 32 (2): 361-369.
- Fauquette S., Guiot J. & Suc J.-P. (1998a). A method for climatic reconstruction of the Mediterranean Pliocene using pollen data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 144: 183-201.
- Fauquette S., Quézel P., Guiot J. & Suc J.-P. (1998b). Signification bioclimatique de taxons-guides du Pliocène Méditerranéen, *Géobios*, 31: 151-169.
- Fauquette S., Suc J.-P., Bertini A., Popescu S.-M., Warny S., Bachiri Taouiq N., Perez Villa M., Chikhi H., Subally D., Feddi N., Clauzon G. & Ferrier J. (2006). How much the climate forced the Messinian salinity crisis? Quantified climatic conditions from pollen records in the Mediterranean region. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 238: 281-301.
- Fauquette S., Suc J.-P., Guiot J., Diniz F., Feddi N., Zheng Z., Bessais E. & Drivaliari A. (1999). Climate and biomes in the West Mediterranean area during the Pliocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 152: 15-36.
- Fauquette S., Suc J.-P., Jimenez-Moreno G., Micheels A., Jost A., Favre E., Bachiri-Taoufiq N., Bertini A., Clet-Pellerin M., Diniz F., Farjanel G., Feddi N. & Zheng Z. (2007).

- Latitudinal climatic gradients in the Western European and Mediterranean regions from the Mid-Miocene (c. 15 Ma) to the Mid-Pliocene (c. 3.5 Ma) as quantified from pollen data. In Williams M., Haywood A.M., Gregory F.J. & Schmidt D.N. (eds.), *Deep-Time Perspectives on Climate Change: Marrying the Signal from Computer Models and Biological Proxies*. The Micropalaeontological Society, Special Publications. The Geological Society, London, pp. 481-502.
- Favre E., François L., Fluteau F., Cheddadi R., Thévenod L. & Suc J.-P. (2007). Messinian vegetation maps of the Mediterranean region using models and interpolated pollen data. *Geobios*, 40 (3): 433-443.
- Ferguson D.K. (1995). Plant part processing and community reconstruction. *Eclogae Geologicae Helvetiae*, 88: 627-641.
- Gaudant J. & Cavallo (2008). The Tortonian-Messinian fish faunas of Piedmont (Italy) and the Adriatic trough: a synthesis dedicated to the memory of Carlo Sturani (1938-1975). *Bollettino della Società Paleontologica Italiana*, 47 (2): 177-189.
- Gentilini G. (1989). The Upper Miocene dragonflies of Monte Castellaro (Marche, Central Italy) (Odonata Libellulidae). *Memorie Società Entomologica Italiana*, 67 (2): 251-271.
- Ghetti P., Anadon P., Bertini A., Esu D., Gliozzi E., Rook L. & Soulié-Marsche I. (2002). The Early Messinian Velona, pre-evaporitic Messinian basin (Siena, Central Italy): paleoenvironmental and paleobiogeographical reconstructions. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 187: 1-33.
- Gregor H.-J. (1990). Contribution to the Late Neogene and Early Quaternary floral history of the Mediterranean. *Review of Palaeobotany and Palynology*, 62: 309-338.
- Grimsson F., Denk T. & Simonarson L.A. (2007). Middle Miocene floras of Iceland - the early colonization of an island? *Review of Palaeobotany and Palynology*, 144 (3-4): 181-219.
- Guglielmetto L. & Iguera L. (1994). Le Gimnosperme fossili del Museo "Federico Eusebio" di Alba. *Alba Pompeia*, 15(2): 31-48.
- Herendeen P.S. (1992). *Podocarpium podocarpum* comb. nov., the Correct Name for *Podogonium knorrii* Heer, nom. illeg. (Fossil Fabaceae). *Taxon*, 41: 731-736.
- Heusser L. & Balsam W.L. (1977). Pollen distribution in the Northeast Pacific Ocean. *Quaternary Research*, 7: 45-62.
- Hou H.-Y. (1983). Vegetation of China with reference to its geographical distribution. *Annals of Missouri Botanical Garden*, 70: 509-548.
- Hsü K.J., Montadert L., Bernoulli D., Cita M.B., Erickson A., Garrison R.E., Kidd R.B., Mélières F., Müller C. & Wright R. (1978). History of the Mediterranean salinity crisis. In Hsü K.J., Montadert L. et al. (eds.), *Initial Reports of the Deep Sea Drilling Project*, 42. US Government Printing Office, Washington DC, pp. 1053-1078.
- Iaccarino S.M., Bertini A., Di Stefano A., Ferraro L., Gennari R., Grossi F., Lirer F., Manzi V., Menichetti E., Ricci Lucchi M., Taviani M., Sturiale G. & Angeletti L. (in press). The Trave section (Monte dei Corvi, Ancona, Central Italy): an integrated paleontological study of the Messinian deposits. *Stratigraphy*.
- Irace A., Dela Pierre F. & Clari P. (2005). "Normal" and "chaotic" deposits in the Messinian Gessoso-solfifera Fm. at the north-eastern border of the Langhe domain (Tertiary Piedmont Basin). *Bollettino della Società Geologica Italiana*, Vol. Spec. 4: 77-85.
- Knobloch E. (1969). Tertiäre floren von Mähren. 201 pp. Moravské Museum Brno-Nusejní spolek, Brno.
- Knobloch E. & Gregor H.J. (1997). Bemerkungen zu den jungtertiären und quartären Blätterfloren Italiens. *Flora Tertiaria Mediterranea*, 5 (2): 1-27.
- Kovar-Eder J., Kvaček Z., Martinetto E. & Roiron P. (2006). Late Miocene to Early Pliocene vegetation of southern Europe (7-4 Ma) as reflected in the megafossil plant record. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 238: 321-399.
- Krijgsman W., Hilgen F. J., Marabini S. & Vai G.B. (1999a). New paleomagnetic and cyclostratigraphic age constraints on the Messinian of the Northern Apennines (Vena del Gesso Basin, Italy). *Memorie della Società Geologica Italiana*, 54: 25-33.
- Krijgsman W., Hilgen F.J., Raffi I., Sierro F.J. & Wilson D.S. (1999b). Chronology, causes and progression of the Messinian salinity crisis. *Nature*, 400: 652-655.
- Kvaček Z. (2004). Early Miocene records of *Craigia* (Malvaceae s.l.) in the Most Basin, North Bohemia - Whole plant approach. *Journal of the Czech Geological Society*, 49 (3-4): 161-171.
- Kvaček Z. (2007). Do extant nearest relatives of thermophile European Cenozoic plant elements reliably reflect climatic signal? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 253: 32-40.
- Kvaček Z., Velitzelos D. & Velitzelos E. (2002). Late Miocene flora of Vegora, Macedonia, N. Greece. 175 pp. University of Athens, Athens.
- Lanini B. (2001). Il Messiniano evaporitico e post-evaporitico in alcune sezioni italiane e spagnole: il contributo palinologico alla ricostruzione paleovegetazionale e paleoclimatica. Unpublished graduation thesis, 102 pp., University of Firenze.
- Lugli S., Manzi V. & Roveri M. (2007). New facies interpretation of the Messinian evaporites in the Mediterranean. C.I.E.S.M. Research Workshop 33 "Messinian Evaporites - From Megadeposits to Micro-biology", Almeria 2007: 67-72.
- Mai D.H. (1995). Tertiäre Vegetationsgeschichte Europas. 676 pp. Gustav Fischer Verlag, Jena.
- Mai D.H. & Martinetto E. (2006). A reconsideration of the diversity of *Symplocos* in the European Neogene on the basis of fruit morphology. *Review of Palaeobotany and Palynology*, 140: 1-26.
- Manchester S.R. (1987). The fossil history of the Juglandaceae - Monographs in Systematic Botany from the Missouri Botanical Garden. 137 pp. Allen Press, Kansas.
- Martinetto E. (1994). Analisi paleocarpologica dei depositi continentali pliocenici della Stura di Lanzo. *Bollettino Museo Regionale di Scienze Naturali di Torino*, 12 (1): 137-172.
- Martinetto E. (1996). Pliocene vegetation at the western margin of the Po Basin. *Allionia*, 34: 349-355.
- Martinetto E. (1999). Chronological framing of Pliocene to Early Pleistocene plant macrofossil assemblages from northern Italy. *Acta Palaeobotanica*, 2: 503-511.
- Martinetto E. (2001). Studies on some exotic elements of the Pliocene floras of Italy. *Palaeontographica*, Abteilung B, 259: 149-166.
- Martinetto E., Bertini A., Bruch A.A., Cilia A. & Kvaček Z. (2007b). Quantitative climatic evaluation of a rich Pliocene leaf, fruit and pollen assemblage from Fossano, NW Italy. *Mio/Pliocene climate in Eastern and Western Eurasia: Comparing data from Europe and China*, Abstract volume: 14.
- Martinetto E., Rista C. & Tarabra E. (2000). Classificazione e ordinamento museologico di foglie di Angiosperme messiniane dell'Albese. *Alba Pompeia*, 21 (1): 3-30.
- Martinetto E., Uhl D. & Tarabra E. (2007a). Leaf physiognomic indications for a moist warm-temperate climate in NW Italy during the Messinian (Late Miocene). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 253: 41-55.
- Massalongo A. (1854). Prodrum florae fossilis senogalliensis. *Giornale del Reale Istituto Lombardo di Scienze, Lettere e Arti*, 5: 1-35.
- Massalongo A. & Scarabelli G.F. (1859). Studii sulla flora fossile e geologia stratigrafica del Senigalliese. 506 pp. Premiata Lit. Penuti, Imola.
- Meller B., Kovar-Eder J. & Zetter R. (1999). Lower Miocene leaf, palynomorph, and diaspore assemblages from the base of the lignite-bearing sequence in the opencast mine Oberdorf, N Voitsberg (Styria, Austria) as an indication of «Younger Mastixioid» vegetation. *Palaeontographica*, Abteilung B, 252: 123-179.
- Nix H. (1982). Environmental determinant of biogeography and evolution in Terra Australis. In Barker W.R. & Greenslade P.J.M. (eds.), *Evolution of the Flora and Fauna of Arid Australia*, Peacock Publ. 47: 9-66.
- Palamarev E. & Ivanov D. (1998). Über einige Besonderheiten der tertiären Floren in Bulgarien und ihre Bedeutung für die



- Entwicklungsgeschichte der Pflanzenwelt in Europa. *Acta Palaeobotanica*, 38: 147-165.
- Paolucci L. (1896). Nuovi materiali e ricerche critiche sulle piante fossili terziarie dei gessi di Ancona. 158 pp. Morelli, Ancona.
- Peola P. (1899a). Flora messiniana di Guarene e dintorni. *Bollettino della Società Geologica Italiana*, 17: 225-255.
- Peola P. (1899b). Florula messiniana di Monte Castello d'Alessandria. *Bollettino della Società Geologica Italiana*, 18: 44-51.
- Popescu S.M., Melinte M.C., Suc J.-P., Clauzon S., Quillévé F. & Suto-Szentai M. (2007). Earliest Zanclean age for the Colombacci and uppermost Di Tetto formations of the "latest Messinian" northern Apennines: New palaeoenvironmental data from the Maccarone, post-evaporitic Messinian section (Marche Province, Italy). *Geobios*, 40: 359-373.
- Prentice I.C., Cramer W., Harrison S.P., Leemans R., Monserud R.A. & Solomon A.M. (1992). A global biome model based on plant physiology and dominance, soil properties and climate. *Journal of Biogeography*, 19: 117-134.
- Principi P. (1926). Flora sarmaziana di Polenta in provincia di Forlì. *Atti della Società Ligure di Scienze e Lettere*, nuova serie, 5 (3): 1-72.
- Reid E.M. (1920). Recherches sur quelques graines pliocènes du Pont-de-Gail (Cantal). *Bulletin Société Géologique de France*, ser. IV, 20: 48-87.
- Rouchy J.M. & Caruso A. (2006). The Messinian salinity crisis in the Mediterranean basin: A reassessment of the data and an integrated scenario. *Sedimentary Geology*, 188-189: 35-67.
- Rouchy J.M., Suc J.P., Ferrandini J. & Ferrandini M. (eds.) (2006). The Messinian salinity crisis revisited. *Sedimentary Geology*, 188: 1-8.
- Roveri M., Bassetti M.A. & Ricci Lucchi F. (2001). The Mediterranean Messinian salinity crisis: an Apennine foredeep perspective. *Sedimentary Geology*, 140: 201-214.
- Roveri M., Landuzzi A., Bassetti M.A., Lugli S., Manzi V., Ricci Lucchi F. & Vai G.B. (2004). The record of Messinian events in the northern Apennines foredeep basins. 44 pp. B19 Field trip guidebook, 32nd International Geological Congress, Firenze, 20-28 Agosto 2004.
- Roveri M. & Manzi V. (2006). The Messinian salinity crisis: looking for a new paradigm? *Palaeogeography, Palaeoclimatology, Palaeoecology*, 238: 386-398.
- Roveri M., Manzi V., Gennari R., Iaccarino S.M. & Lugli S. (2008). Recent advancements in the Messinian stratigraphy of Italy and their Mediterranean-scale implications. *Bollettino della Società Paleontologica Italiana*, 47 (2): 71-85.
- Roveri M., Manzi V., Ricci Lucchi F. & Rogledi S. (2003). Sedimentary and tectonic evolution of the Vena del Gesso basin (Northern Apennines, Italy): Implications for the onset of the Messinian salinity crisis. *Geological Society of America Bulletin*, 115: 387-40.
- Sachse M. (2001). Oleaceous laurophyllous leaf fossils and pollen from the European Tertiary. *Review of Palaeobotany and Palynology*, 115: 213-234.
- Satoo T. (1983). Temperate broad-leaved evergreen forests of Japan. In Ovington J.D. (ed.), Temperate broad-leaved evergreen forests. 241 pp., Elsevier, Amsterdam.
- Schimper A.F.W. (1898). Pflanzengeographie auf physiologischer Grundlage. *Historiae Naturalis Classica II*. 876 pp. Wheldon and Wesley, Codicote, repr. Cramer, Weinheim (1964).
- Spicer R.A. & Wolfe J.A. (1987). Plant taphonomy of late Holocene deposits in Trinity (Clair Engle) Lake northern California. *Paleobiology*, 13 (2): 227-245.
- Suc J.-P., Bertini A., Combourieu-Nebout N., Diniz F., Leroy S., Russo-Ermolli E., Zheng Z., Bessais E. & Ferrier J. (1995a). Structure of West Mediterranean vegetation and climate since 5.3 Ma. *Acta Zoologica Cracoviensis*, 38 (1): 3-16.
- Suc J.-P. & Bessais E. (1990). Pérennité d'un climat thermo-xérique en Sicile avant, pendant, après la crise de salinité messinienne. *Comptes rendus de l'Académie des Sciences*, 294: 1003-1008.
- Suc J.-P., Diniz F., Leroy S., Poumot C., Bertini A., Dupont L., Clet M., Bessais E., Zheng Z., Fauquette S. & Ferrier J. (1995b). Zanclean (~ Brunsumian) to early Piacenzian (~ early -middle Reuverian) climate from 4° to 54° north latitude (West Africa, West Europe and West Mediterranean areas). *Mededelingen Rijks Geologische Dienst*, 52: 43-56.
- Suc J.-P., Fauquette S., Bessedik M., Bertini A., Zheng Z., Clauzon G., Suballyova D., Diniz F., Quezel P., Feddi N., Clet M., Bessais E., Bachiri Taoufiq N., Méon H. & Combourieu-Nebout N. (1999). Neogene vegetation changes in West European and West circum-Mediterranean areas. In Agusti J., Rook L. & Andrews P. (eds.), Hominoid Evolution and Climatic change in Europe, Cambridge Univ. Press, 1: 378-388.
- Suc J.P., Violanti D., Londeix L., Poumot C., Robert C., Clauzon G., Gautier F., Turon J.L., Ferrier J., Chikhi H. & Cambon G. (1995c). Evolution of the Messinian Mediterranean environments: the Tripoli Formation at Capodarso (Sicily, Italy). *Review of Palaeobotany and Palynology*, 87: 51-79.
- Trevisan L. (1967). Pollini fossili del Miocene superiore nei Tripoli del Gabbro (Toscana). *Palaeontographia Italica*, 62: 1-75.
- Vai G.B. (1997). Cyclostratigraphic estimate of the Messinian stage duration. In Montanari A., Odin G.S. & Coccioni R. (eds.), Miocene Stratigraphy - An Integrated Approach. Elsevier, Amsterdam: pp. 463-476.
- Vai G.B. & Ricci Lucchi F. (1977). Algal crusts, autochthonous and clastic gypsum in a cannibalistic evaporite basin: a case history from the Messinian of northern Apennines. *Sedimentology*, 24: 221-244.
- Van der Burgh J. (1983). Allochthonous seed and fruit floras from the Pliocene of the Lower Rhine Basin. *Review of Palaeobotany and Palynology*, 40: 33-90.
- Van der Burgh J. & Zetter R. (1998). Plant mega- and microfossil assemblages from the Brunsumian of "Hambach" near Düren, B.R.D. *Review of Palaeobotany and Palynology*, 101: 209-256.
- Vidal L., Bickert T., Wefer G. & Röhl U. (2002). Late Miocene stable isotope stratigraphy of SE Atlantic ODP Site 1085: Relation to Messinian events. *Marine Geology*, 180: 71-85.
- Violanti D., Martinetto E. & Pavia M. (2003). Giornate di Paleontologia 2003. Guida alle Escursioni. 59 pp. Dip. Scienze Terra, Torino.
- Viviani V. (1833). Sur les restes de plantes fossiles trouvés dans les gypses tertiaires de Stradella près de Pavie. *Mémoires de la Société Géologique de France*, 1 (1): 129-134.
- Walther H. & Zetter R. (1993). Zur Entwicklung der paläogenen Fagaceae Mitteleuropas. *Palaeontographica*, Abteilung B, 239: 183-194.
- Wang C.W. (1961). The forests of China with a survey of grassland and desert vegetation. 313 pp. Maria Moores Cabot Foundation Publ. ser. 5, Harvard Univ., Cambridge, Massachusetts.
- Ying T.S. (1983). The floristic relationships of the temperate forest regions of China and the United States. *Annals of Missouri Botanical Garden*, 70: 597-604.
- Zheng Z. (1990). Végétations et climats néogènes des Alpes maritimes franco-italiennes d'après les données de l'analyse palynologique. *Paléobiologie Continentale*, 17: 217-244.

Manuscript received 05 February 2008

Revised manuscript accepted 14 June 2008

